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# Modality and language acquisition: How does the channel through which language is expressed affect how children and adults are able to learn?

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# Modality and language acquisition: How does the channel through which language is expressed affect how children and adults are able to learn?

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# Editorial: Modality and language acquisition: how does the channel through which language is expressed affect how children and adults are able to learn?

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**modality, language acquisition, sign language, L2 acquisition, spoken language, multimodality, gesture, deafness**

Editorial on the Research Topic
Modality and language acquisition: how does the channel through which language is expressed affect how children and adults are able to learn?

The most fundamental way in which human languages vary—their most essential typological dimension—lies in their "modality" of production and perception. Human languages may be spoken or signed, and perceived through hearing, vision, or touch. Oral-aural and visual-gestural languages are the native languages of substantial communities; tactile-gestural linguistic systems include the now-emerging languages of deaf-blind communities (Edwards, 2014; Edwards and Brentari, 2020; in this Research Topic, see Villwock and Grin, for a review of the perception of touch in sighted deaf individuals and deaf-blind individuals). That languages exist in these three modalities, or transmission channels, is testament to the plasticity of the human language capacity, and to its resilience.

In this Research Topic, our contributors examine a number of hypothesized differences between the visual-gestural and auditory-vocal modalities. "Modality differences" between languages are attributable to the differing resources and constraints of their respective transmission channels. For example, given the affordances of the visual-gestural modality, iconicity – the motivated, non-arbitrary relationship between a linguistic symbol's form and its meaning – appears to be more frequent in signed than in spoken languages; the role of iconicity in the learning of signed languages is examined here in Gappmayr et al., Hofweber et al., and Kurz et al.. Attention to iconicity in the sign literature may have been one factor that has pushed researchers on spoken languages to recognize that not everything is arbitrary in speech (e.g., Dingemanse et al., 2015).

Another property of signing has no obvious analog in speech. In sign, the manual articulators are the object of perception, unlike the oral articulators, which are largely hidden from view. One consequence is that many signs look quite different from the addressee's perspective than the signer's (Shield and Meier, 2018). Shield et al. argue that this phenomenon contributes to a distinctive characteristic (palm reversals) of the signing of deaf autistic children.

The phonological and morphological organization of signs appears to be more simultaneously-, and less sequentially-, structured than are the words of spoken languages. Consistent with this typological generalization, Gu et al. find that sequential complexity, but much less so simultaneous complexity, is a source of difficulty in children's imitation of pseudosigns. Yet, as Loos et al. observe in their contribution, sequentially-organized structures appear in signing in places where we might have anticipated simultaneity, whether in children's acquisition of signed languages as first languages, in the emergence of new signed languages, or in the grammar and adult usage of established signed languages.

Multimodality is not just a manifestation of the plasticity of the human language capacity, as important as that is. Instead, learners and users confront it every day. Hearing, sighted users of spoken languages integrate visual information from co-speech gesture with the auditorily-presented speech stream. Adult hearing learners of a signed language are not just learning a second language, they are learning a language in a new modality; several contributions discuss these so-called L2M2 learners (Hofweber et al.; Schönström and Holmström; Kurz et al.; Watkins et al.; Joyce et al.). Spoken languages are not only presented auditorily, but can also be represented visually through writing. Deaf individuals often learn a spoken language primarily through its writing system, as Caldwell-Harris and Hoffmeister and Hänel-Faulhaber et al. observe in this Research Topic. For deaf learners, their acquisition of a first, signed language may enable success in the visual learning of a spoken language (Mayberry et al., 2002).

The issues of multimodality, iconicity and phonological-morphological organization have been widely discussed in research on second-language acquisition by hearing learners of a first signed language. For example, sign frequency and iconicity facilitate sign recognition, whereas individual differences in cognitive abilities and language learning background seemingly play no role (Hofweber et al.). There are novel findings reported here: (a) disability does not appear to impact the phonological discrimination and perspective-taking abilities of adult L2M2 learners (Joyce et al.), (b) nonlinguistic visuospatial skills, including visuospatial working memory and mental rotation skills, are predictive of success in sign-language interpreting programs (Watkins et al.), and (c) compared to L2M1 learners, L2M2 learners tend to have greater difficulty acquiring those parts of the lexicon that are specific to signed languages, such as depicting signs (Schönström and Holmström). Kurz et al. closely examined the use of four types of depicting signs in short narratives produced by L2M2 learners; these types showed different learning trajectories.

Within the field of first-language (L1) acquisition studies, three modality-related issues are explored in some detail in this Research Topic: visual attention, age of acquisition, and the effects of such linguistic properties as the phonological structure of words vs. signs. Novack et al.'s findings indicate that infants allocate their visual attention differently to people and objects depending on the modality of the language that is being used. Later in development, hearing children (aged 2–8 years) who were natively exposed to sign pay more attention to the face during the production of ASL signs than do sign-naive children, but not so during the production of non-linguistic grooming or of mime gestures (Bosworth et al.). Singleton and Crume show that deaf children of Deaf parents already have finely-attuned visual attention abilities by the time they start preschool, while deaf children of hearing parents do not. Adding to these findings, Tomaszewski et al. find that deaf children growing up in deaf families outperform deaf children from non-deaf families on measures of phonological, morphological, and syntactic competence in Polish Sign Language. In addition to considering the impact of language experience on somatosensory processing, Villwock and Grin point out that sensory deprivation plays a role in the highly variable acquisition experiences of deaf and deafblind children. Finally, Gu et al. discuss modality-related similarities and differences in children's phonological development by comparing results from pseudo-sign and pseudo-word repetition tasks. More cross-modal experimental approaches are needed and will enhance our understanding of modality-specific and modality-independent properties of language acquisition.

Modality of language has broader impacts in society. In the realm of education, Singleton and Crume observe that the enhanced visual-attention abilities of deaf preschoolers from Deaf families lead teachers to direct fewer attention-directing cues and more positive participation cues to them than to deaf preschoolers from hearing families, showing that early exposure to a signed language leads to better classroom interactions even in preschool. Despite the importance of the classroom as a site for sign learning, Goppelt-Kunkel et al. find that the presence of a single deaf peer or deaf educator in an inclusive kindergarten group is not sufficient to encourage hearing children in that classroom to use signs. Finally, Horton and Singleton examine the complex ways that modality of language affects the turn-taking skills of deaf children acquiring sign languages in a variety of settings, including the classroom.

Modality also has implications for the concept of neurodiversity, which in recent years has lifted discussions of atypical conditions from the realm of disorder and helped shift researchers to an appreciation of differences. Shield et al. consider how studying deaf autistic signers can inform our understanding of modality effects in signed and spoken languages, while Villwock and Grin point to the need for more research on the language acquisition of deafblind individuals in order to better understand the differential impacts of sensory deprivation vs. language experience on neuroplasticity and somatosensory processing. Lastly, Joyce et al. use the construct of disability to analyze the intersection of language, modality, and cognition, finding that the signed modality does not disadvantage neurodiverse learners.

Finally, we note that most of the authors who are published in this Research Topic have spent their careers working largely on signed languages. We had hoped to receive more submissions from researchers who work primarily on spoken languages. But we think too few researchers on spoken languages are delving into how the resources and constraints of the oral-aural modality may shape the organization of spoken languages. Researchers on spoken languages should, in our view, be more attentive to this problem. In contrast, the possible effects and non-effects of language modality are front and center in the sign literature, perhaps because all researchers working on signed languages are also familiar with spoken languages, or perhaps because spoken languages remain a default against which signed languages are inevitably compared. Indeed knowledge of the linguistics of spoken languages may sometimes skew our analyses of signed languages, thereby obscuring differences between sign and speech. In the future, we hope to see more attention to the effects of language modality on the structure and acquisition of language, not just by researchers on signed languages, but by researchers from across the language sciences.

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## References

Dingemanse, M., Blasi, D. E., Lupyan, G., Christiansen, M. H., and Monaghan, P. (2015). Arbitrariness, iconicity, and systematicity in language. *Trends Cognit. Sci.* 19, 603–615. doi: 10.1016/j.tics.2015.07.013

Edwards, T. (2014). *Language Emergence in the Seattle DeafBlind Community (Doctoral Dissertation)*. Berkeley, CA: UC Berkeley.

Edwards, T., and Brentari, D. (2020). Feeling phonology: the conventionalization of phonology in protactile communities in the United States. *Language* 96, 819–840. doi: 10.1353/lan.2020.0063

Mayberry, R. I., Lock, E., and Kazmi, H. (2002). Linguistic ability and early language exposure. *Nature.* 417, 38.

Shield, A., and Meier, R. P. (2018). Learning an embodied visual language: four imitation strategies available to sign learners. *Front. Psychol.* 9, 811. doi: 10.3389/fpsyg.2018.00811

ORIGINAL RESEARCH
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# Breaking Into Language in a New Modality: The Role of Input and Individual Differences in Recognising Signs

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A key challenge when learning language in naturalistic circumstances is to extract linguistic information from a continuous stream of speech. This study investigates the predictors of such implicit learning among adults exposed to a new language in a new modality (a sign language). Sign-naïve participants ($N = 93$; British English speakers) were shown a 4-min weather forecast in Swedish Sign Language. Subsequently, we tested their ability to recognise 22 target sign forms that had been viewed in the forecast, amongst 44 distractor signs that had not been viewed. The target items differed in their occurrence frequency in the forecast and in their degree of iconicity. The results revealed that both frequency and iconicity facilitated recognition of target signs cumulatively. The adult mechanism for language learning thus operates similarly on sign and spoken languages as regards frequency, but also exploits modality-salient properties, for example iconicity for sign languages. Individual differences in cognitive skills and language learning background did not predict recognition. The properties of the input thus influenced adults' language learning abilities at first exposure more than individual differences.

**Keywords: second language learning, iconicity, sign languages, implicit learning, first exposure, modality**

## INTRODUCTION

Much language learning around the world takes place not in classroom settings involving explicit instruction but in contexts involving uninstructed, implicit learning. For example, many of us have travelled to countries where we do not speak the local language and have switched on the TV to watch the weather forecast in order to check if we will need an umbrella later that day. When confronted with novel input, the human brain cannot help but engage in implicit statistical learning processes (see Christiansen, 2019, for a discussion of this term). But how much can individuals learn about word forms in a new language from exposure to a short stretch of continuous language without training or instruction, and which language features and cognitive skills predict learning? These issues have received a lot of attention in second language acquisition research under different labels, such as incidental and implicit learning (DeKeyser, 2003; Hulstijn, 2003; Williams and Rebuschat, 2012), usage-based approaches (e.g., Ellis, 2012; Ellis and Wulff, 2020), statistical learning (e.g., Rebuschat and Williams, 2012; Christiansen, 2019) and artificial language learning (e.g., Saffran et al., 1997). This work has focused on spoken and written language. However, the problem of breaking down continuous linguistic input generalises to sign languages. Yet in sign languages much less is known about how this is achieved.

Here, we undertake the first study to investigate how adults who are naïve to sign languages break into a naturalistic stream of signs at first exposure. Specifically, we investigate whether sign-naïve viewers of a short video of naturalistic sign language can identify which sign forms they have and have not viewed and which features of the signed input and which cognitive skills are associated with successful identification. We aim to elucidate the features and skills that are common to learning across languages, regardless of modality, and those that might be particularly relevant to the learning of sign languages. In terms of the input, we zoom in on two factors predicted to influence sign language learning, i.e., frequency and iconicity.

## BACKGROUND

### Input Processing

A pre-requisite for lexical acquisition is to identify word forms, and a key challenge for individuals who learn languages outside of classroom settings is to break down the continuous stream of naturalistic input to identify such strings. Since language does not come neatly segmented with words resembling 'beads on a string', this task requires learners to work on the input. This is one of the learner's 'problems of analysis', as Klein (1986) puts it. A considerable body of research on spoken/written language has revealed that babies and adults alike appear to have sophisticated cognitive mechanisms for identifying word forms in a novel speech stream, which do not depend upon explicit instruction as to where word boundaries lie. Rather, a powerful statistical mechanism seems to keep track of frequency and transitional probabilities between adjacent and non-adjacent items to help identify patterns that translate into word forms and word boundaries, but also morphosyntactic and phonotactic patterns. For example, a range of studies has shown that child and adult learners are able to track the frequency of syllables and word forms for learning in both spoken (e.g., Saffran et al., 1996; Gomez and Gerken, 1999; Maye et al., 2002; De Diego Balaguer et al., 2007; Peters and Webb, 2018; Rodgers and Webb, 2020) and written contexts (e.g., Horst et al., 1998; Hulstijn, 2003; Waring and Takaki, 2003; Webb, 2005; Pigada and Schmitt, 2006; Pellicer-Sánchez, 2016). Generally speaking, higher frequency (both type and token) is associated with better learning. For example, Ellis et al. (2016) found that untutored learners of L2 English in the so-called ESF corpus (Perdue, 1993) acquired the most frequent and prototypical verbs in the input first (e.g., *put* and *give*), with a very high correlation between input frequency and learning. Moreover, type/token frequency and distributional properties have also been shown to interact with the salience of form, the importance of meaning, and the reliability of the form-meaning mappings (Ellis and Collins, 2009). Finally, the statistical capacity also operates on non-adjacent structures and situations. In a seminal paper, Yu and Smith (2007) showed that adults are able to track a particular word form across several situations when multiple possible referents are available, to ultimately determine the intended referent. This capacity for cross-situational learning also seems to scale up. Rebuschat et al. (2021) showed that adults are able to learn both vocabulary and grammar, words from different word classes, and in ambiguous contexts, which suggests a very powerful mechanism.

A great deal of research on input processing has drawn on the use of artificial languages, semi-artificial languages, or miniature languages, which provide researchers with total control over the distributional properties of the input to which learners are exposed (for useful overviews and discussions of these paradigms, see Hayakawa et al., 2020, for the lexicon; Grey, 2020, for morphosyntax; Morgan-Short, 2020, for neural underpinnings). While artificial languages have the advantage of allowing close experimental control over the properties of the input, their ecological validity has been questioned and in particular whether the properties of artificial and natural languages lead to the same learning outcomes and generalisations (e.g., Robinson, 2005, for a discussion). Nevertheless, much less work has been conducted on natural languages. A rare exception is a study by Kittleson et al. (2010) who tested implicit learning of Norwegian and showed that adults from different language backgrounds who were presented with continuous Norwegian speech in an implicit learning paradigm could segment the Norwegian speech stream and distinguish words from non-words after minimal exposure. Several studies have attempted to study the effects of input frequency as well as cognate status in classroom settings in which learners with different L1s were exposed to teachers of Polish with more or less control over actual input (Rast, 2008; Dimroth et al., 2013). Another series of experiments have attempted to emulate acquisition 'in the wild', or at least in a context replicating real-world context, while maintaining control over the input (Gullberg et al., 2010, 2012). In these studies, adults were exposed to 7 min of continuous and coherent speech in a language unknown to them, namely, Mandarin Chinese, in the form of a filmed weather forecast (Gullberg et al., 2010, 2012). Participants then undertook surprise tests of word recognition, word-meaning mapping, or phonological plausibility (as measured by lexical decision). The results suggested that adults exposed to naturalistic input in a novel language extracted information about this language without any additional explicit instructions (Gullberg et al., 2010) and that item frequency boosted word recognition, meaning mapping and phonotactic generalisation alike. Moreover, adults' brains showed evidence of change in resting state connectivity as a function of such learning after only 14 min of exposure to continuous speech (Veroude et al., 2010).

### Sign Languages

The problem of breaking down continuous linguistic input generalises to sign languages, yet in sign languages still less is known about how this is achieved, even in artificial language learning situations (exceptions are Orfanidou et al., 2010, 2015). The literature on spoken/written languages suggests that item frequency should matter for sign language too, but this prediction has not yet been tested.

Another important feature of sign languages is iconicity. Iconicity can be defined as a resemblance between a linguistic form and its meaning, where aspects of the form and meaning are related by perceptual and/or motor analogies (Sevcikova Sehyr and Emmorey, 2019). For example, in Swedish Sign Language, the sign for SNOW involves the open hands moving downwards as the fingers wiggle, resembling the movement of falling snowflakes. Although it has been argued that iconic mappings between form and meaning are more plentiful in speech than previously acknowledged (Perniss et al., 2010; Dingemanse et al., 2015), the visuo-gestural modality allows particularly rich opportunities for iconicity. It has also been argued that iconicity plays an important role for language learning. In spoken language acquisition, iconic manual gestures have been shown to boost L2 vocabulary acquisition in intervention studies, especially when learners repeat both spoken word form and gesture (see Gullberg, 2022, for an overview). In the case of sign language acquisition, the effects of iconicity on adult lexical acquisition are mixed (Ortega, 2017, provides a review) with positive effects on conceptual-semantic learning, but more mixed effects on form learning. It has also been suggested that in hearing learners of sign languages, the existing repertoire of iconic co-speech gestures may serve as a substrate for acquisition, facilitating form-meaning mappings in sign languages even at first exposure (Janke and Marshall, 2017; Ortega et al., 2019).

## Individual Cognitive Skills

Although all humans share the ability to acquire languages across the lifespan, research on second language acquisition of spoken languages suggests that individual differences affect the success of second language acquisition (Robinson, 2001; Paradis, 2011; Granena et al., 2016; Dörnyei and Ryan, 2015). For example, the influence of demographic factors, such as age on the ability to acquire another language, continues to be debated in the field (Birdsong, 2005; Singleton and Pfenninger, 2018). Moreover, cognitive abilities and executive functions, most notably phonological working memory, have been suggested to influence spoken language learning (O'Brien et al., 2007; Baddeley, 2017; Wen and Li, 2019). Another important factor affecting individuals' ability to acquire another spoken language is their language aptitude, as measured by language learning aptitude tests (e.g., Meara, 2005; Artieda and Muñoz, 2016; Li, 2018). This raises the question of how variables that have been shown to modulate spoken second language acquisition operate when individuals acquire a new language in the visual modality.

To date, few studies have looked at the role of individual differences when learning sign languages. Existing studies of sign language learning under explicit conditions suggest that spoken vocabulary knowledge (Williams et al., 2017) and kinaesthetic and visuo-spatial short-term memory (Martinez and Singleton, 2018) predict learning of sign vocabulary, but that verbal short-term/working memory (Williams et al., 2017) and knowledge of other spoken languages (Martinez and Singleton, 2019) do not. However, the role of cognitive predictors in sign learning under implicit conditions at first exposure remains unstudied.

## The Current Study

In the current study, participants viewed 4 min of naturalistic, continuous sign language input in the form of a weather forecast presented in Swedish Sign Language (STS). Immediately after watching the forecast, they undertook a 'surprise' sign recognition task and judged whether or not individually presented signs had appeared in the forecast. Some of these signs had indeed appeared in the weather forecast ('target signs') but others had not ('distractor signs'). We manipulated the frequency and iconicity of targets. With respect to the distractors, half were real signs of STS that had not appeared in the forecast but were phonologically similar to the targets ('plausible distractors'), and half were *not* from STS: they were real signs of other languages, but they involved phonological features that are dispreferred (i.e., occur less frequently) across sign languages ('implausible distractors'). Participants also completed a language background questionnaire and undertook a battery of tasks assessing their cognitive abilities (fluid intelligence, executive functions, visual attention, language learning aptitude, and L1 vocabulary knowledge; see the section 'Materials and Procedures'. for detailed descriptions of the protocol). Our research questions and predictions were as follows:

1. Can sign-naïve adults successfully discriminate between signs that did appear in the forecast and signs that did not, and does doubling the exposure (to 8 min) increase performance accuracy?

We predicted that although the task would be difficult, participants would distinguish between signs that they had viewed ('target signs') and signs that they had not viewed ('distractor signs'). Furthermore, we predicted that performance accuracy would be enhanced by viewing the input twice compared to just once and that performance would be modulated by the input factors outlined in research questions 2 and 3, below.

2. Do frequency and iconicity impact how accurately target signs are recognised?

We predicted that for target signs, those with greater occurrence frequency in the input would be recognised more accurately. We also predicted that target signs with greater iconicity would be recognised more accurately.

3. Does phonotactic plausibility impact how accurately distractor signs are identified?

For distractor signs, we predicted that those that were phonologically implausible would be identified more accurately as not having been viewed in the input compared to signs that were phonologically plausible.

4. Which participant characteristics and cognitive skills are associated with greater recognition accuracy for target signs?

Finally, we predicted that performance accuracy would be modulated by age, education, fluid intelligence, executive functions, visual attention, language learning aptitude, L1 vocabulary, and degree of multilingualism.

# MATERIALS AND METHODS

## Participants

Our study was pre-registered on the Open Science Framework.[1] In the pre-registration, we had indicated that we would test 100 participants, but data collection was suspended prematurely due to the onset of the COVID-19 crisis in spring 2020, resulting in a final sample size of 93. All participants were sign-naïve adults who were native speakers of English and resident in the United Kingdom. None had any known physical, sensory, or psychological impairments relevant to this study. Participants were randomly allocated to two Exposure groups: Exposure group 1x watched the weather forecast once ($N = 50$), Exposure group 2x watched the weather forecast twice back-to-back ($N = 43$). Their demographic and linguistic background was ascertained with a detailed questionnaire (see https://osf.io/ub28n/?view_only=fce4401c7284438d94d1ce52c7879733), administered immediately after the experiment using free online software (Surveymonkey, www.surveymonkey.co.uk). The general outline of our questionnaire was based on the Language History Questionnaire 2.0 (Li et al., 2014) but we created a bespoke set of questions tailored to our specific requirements. For instance, participants gave information on any prior exposure to sign languages, Makaton, fingerspelling or Swedish, because existing skills in these areas were exclusion criteria. We assessed education using two measures: (1) total number of years spent in formal education and (2) highest education level (1 = A-Level, 2 = Bachelor degree, 3 = post-graduate degree, and 4 = doctoral degree). Participants were aged between 18 and 40. The upper age limit was applied due to the reported detrimental effects of Age on some of our key variables, in particular on visual search abilities (Hommel et al., 2004). Although we aimed for a comparable gender split between groups, our groups could not be gender-matched due to the interruption of data collection in spring 2020: Exposure group 1x has marginally more females (females: 84%, $N = 42$, males: 16%, $N = 8$) than Exposure group 2x (females: 63%, $N = 27$, males: 37%, $N = 16$) [Chi-squared $(1,93) = 5.34$, $p = 0.05$].

Given that individuals' language background impacts upon their ability to benefit from naturalistic input (Ristin-Kaufmann and Gullberg, 2014), we assessed participants' language history and usage. Our data set comprised both monolinguals and multilinguals, but we kept language dominance profiles constant: all participants were native speakers of English and reported English as their most commonly used language. However, we predicted that variability in the degree of multilingualism would affect performance on the sign recognition task, so in our measures, components of multilingualism were classed as continuous, rather than categorical, to do justice to the high levels of individual variability that characterise the phenomenon of multilingualism (Luk and Bialystok, 2013). For each of their languages, participants reported Age of Onset, the current frequency of usage (six-point Likert scale), and the extent to which their languages had been acquired through explicit vs. implicit learning (six-point Likert scale, ranging from 'mostly formal' to 'mostly informal'). This information generated the following set of predictors for our regression analyses: number of languages learnt, number of additional languages, multilingual usage scores (sum of frequency scores reported for each language), number of languages acquired in an informal context that is through implicit learning. Finally, participants were asked to report the frequency with which they engaged in code-switching between languages (six-point Likert scale) as this may modulate executive functions, which in turn benefit language learning (Hofweber et al., 2020).

**Table 1** presents descriptive statistics for the demographic and linguistic variables from the questionnaire and inferential statistics from a multivariate ANOVA with the between-group variable Exposure group (exposure 1x vs. exposure 2x) and the various background variables as dependent variables. This revealed that the two groups did not differ on any background variables, although the group difference in Age approached significance [$F(1,92) = 3.96$, $p = 0.05$, $\eta^2 = 0.04$]. Moreover, there was a slight trend for Exposure 1x group to display greater levels of multilingualism than Exposure 2x group, as evidenced by a greater number of languages overall and of additional languages, but these differences did not reach significance. All participants completed a test battery assessing their cognitive abilities, such as executive functions, language aptitude, L1 vocabulary knowledge and fluid intelligence (see section 2.2.3. for details). **Table 2** presents a comparison of cognitive background measures for each exposure group. A multivariate ANOVA with Exposure group (1x, 2x) as the between-subject variable revealed that the 1x Exposure group performed better at Kinaesthetic working memory and Llama D, but displayed less good visual search abilities. Thus, the background measures suggest that the two Exposure groups were matched on the most crucial background variables, such as Age, Fluid Intelligence, and executive functions, but differed slightly on Kinaesthetic working memory, Llama D, and visual search abilities.

## Materials and Procedures

Our experimental protocol was approved by the first and last authors' institutional review board and was carried out in accordance with the provisions of the World Medical Association Declaration of Helsinki. All tasks were administered in the same session on the same day. The overall duration of the experimental protocol was 1.5 h. The protocol followed a blended approach combining fixed and counterbalanced administration orders. To avoid priming from other tasks, participants first conducted the implicit learning task, i.e., the weather forecast in Swedish Sign Language. They were not aware that they would be tested on the weather forecast content afterwards. Immediately after viewing the forecast, participants undertook a 'surprise' sign recognition task, in which they indicated whether or not they recognised signs from the forecast. Following the administration of the weather forecast materials, participants completed the online background questionnaire. After that, a battery of individual differences tasks was administered: five executive function tasks (administered in a partially counterbalanced order), three verbal tasks, and a task assessing fluid intelligence. All tasks were administered face-to-face on

[1] https://osf.io/ub28n/?view_only=fce4401c7284438d94d1ce52c7879733

**TABLE 1** | Demographic and linguistic background variables by exposure group.

| Variables | Group | *Mean* | *SD* | *F* | *p* | $\eta^2$ |
|---|---|---|---|---|---|---|
| Age (years) | Exposure 1x | 25.56 | 6.38 | 3.96 | 0.05 | 0.04 |
| | Exposure 2x | 28.19 | 6.30 | | | |
| Education (years) | Exposure 1x | 17.20 | 2.72 | 1.05 | 0.31 | 0.01 |
| | Exposure 2x | 17.81 | 3.06 | | | |
| Education (level) | Exposure 1x | 2.60 | 0.76 | 0.07 | 0.80 | 0.00 |
| | Exposure 2x | 2.56 | 0.83 | | | |
| Languages (number) | Exposure 1x | 4.02 | 1.24 | 3.26 | 0.07 | 0.03 |
| | Exposure 2x | 3.60 | 0.93 | | | |
| Non-native languages (number) | Exposure 1x | 2.76 | 1.27 | 3.26 | 0.06 | 0.04 |
| | Exposure 2x | 2.30 | 1.01 | | | |
| Multilingual usage score (sum of frequencies) | Exposure 1x | 12.50 | 3.83 | 0.17 | 0.68 | 0.00 |
| | Exposure 2x | 12.19 | 3.34 | | | |
| Informally acquired languages (number) | Exposure 1x | 2.10 | 0.96 | 0.72 | 0.40 | 0.01 |
| | Exposure 2x | 2.28 | 1.03 | | | |
| Code-switching frequency (1–6) | Exposure 1x | 2.26 | 1.40 | 1.87 | 0.18 | 0.02 |
| | Exposure 2x | 1.84 | 1.59 | | | |

**TABLE 2** | Cognitive background variables by exposure group.

| Variables | Group | *Mean* | *SD* | *F* | *p* | $\eta^2$ |
|---|---|---|---|---|---|---|
| Fluid intelligence (WAIS matrices) | Exposure 1x | 21.58 | 2.43 | 0.01 | 0.93 | 0.00 |
| | Exposure 2x | 21.63 | 2.79 | | | |
| Inhibitory control (flanker effect) | Exposure 1x | 61.03 | 17.76 | 0.01 | 0.93 | 0.00 |
| | Exposure 2x | 60.69 | 20.17 | | | |
| Phonological working memory (digit span) | Exposure 1x | 10.76 | 2.10 | 0.04 | 0.85 | 0.00 |
| | Exposure 2x | 10.67 | 2.26 | | | |
| Visuo-spatial working memory (Corsi span) | Exposure 1x | 6.14 | 1.26 | 1.53 | 0.22 | 0.02 |
| | Exposure 2x | 5.84 | 1.07 | | | |
| Kinaesthetic working memory | Exposure 1x | 10.92 | 1.59 | 4.75 | 0.03 | 0.05 |
| | Exposure 2x | 10.06 | 2.19 | | | |
| Visual search load effect | Exposure 1x | 254.78 | 159.54 | 11.69 | 0.001 | 0.11 |
| | Exposure 2x | 164.43 | 72.68 | | | |
| Llama B (language aptitude) | Exposure 1x | 57.80 | 18.16 | 1.55 | 0.22 | 0.02 |
| | Exposure 2x | 53.02 | 18.81 | | | |
| Llama D (language aptitude) | Exposure 1x | 29.80 | 13.01 | 4.091 | 0.046 | 0.04 |
| | Exposure 2x | 23.95 | 14.86 | | | |
| L1 vocabulary (WAIS) | Exposure 1x | 38.74 | 5.98 | 0.011 | 0.92 | 0.00 |
| | Exposure 2x | 38.88 | 7.43 | | | |

an individual basis in a lab setting using a Dell XPS 13 Laptop with a 13-inch screen. The following sub-sections describe the materials and procedures. All materials related to the STS weather forecast, sign recognition task and iconicity rating task are available at https://osf.io/ub28n/?view_only=fce4401c7284438d94d1ce52c7879733.

## Naturalistic Input: Weather Forecast in Swedish Sign Language

The weather forecast is a particular discourse type aimed at the general public and likely to be familiar to most people. It functions within a fairly rigid framework, whereby listeners/viewers have expectations about the sorts of words (e.g., weather types, temperatures, geographical locations, and times of the day/days of the week), images (e.g., a map of a country overlain with weather symbols), and gestures (e.g., points to areas of the map) that will occur (Moore Mauroux, 2016). This discourse type was chosen not only because it was used in previous first-exposure studies of spoken language (Gullberg et al., 2010, 2012), but also because it could be adapted for presentation in Swedish Sign Language and still retain its familiarity for viewers.

Few examples of weather forecasts delivered in sign languages exist. Most are interpretations into sign language of a spoken language forecast, whereby the signing interpreter is not directly in front of the weather map but is to the edge of the screen and it is the speaking forecaster who is interacting directly with the map. We required a forecast in which the forecaster interacts directly with the map and wanted to maintain experimental control of sign frequency, so we created a weather forecast specifically for this project. The script was originally written in English, then translated into Swedish and then interpreted by a professional interpreter from Swedish into Swedish Sign Language (STS). The aim was to create as natural, engaging and professional-looking a forecast as possible given our constraints. By using STS as a target language, we avoided a sign language where the mouthings could be related to the sound patterns of English words: we did not want English participants to extract information about signs' meanings from the signer's lip movements.

Our weather forecast video lasted 4 min and was constructed around 22 target signs that covered a variety of semantic meanings relevant to a weather forecast, including weather-related words (e.g., *rain*, *sun*, and *cloud*), temperature-related words (e.g., *warm*, *cold*, and particular numbers), geography-related words (e.g., *north*, *south*, and *mountain*), and time-related words (*today*, *night*). An important experimental manipulation was that the 22 target signs varied in their occurrence frequency. Eleven of them occurred eight times in the forecast, whilst the other eleven occurred three times [there was one exception: the item 'SÖDER' (south) appeared four times instead of three times; the additional token was introduced by mistake during the translation stage from English to Swedish]. The former set was therefore designated 'high frequency' signs, the latter 'low frequency' signs. Both sets were matched for aspects of sign language phonology, namely for locations of signs and hand configurations and for the number of one-handed signs vs. two-handed signs where both hands move, vs. two-handed signs where the active hand contacts a static non-dominant hand.

The target signs were also matched for iconicity, with both sets containing items that ranged from low to high iconicity on the basis of ratings from an independent group of 24 British English-speaking sign-naïve raters. Iconicity of the target items was assessed using an iconicity rating task based on Motamedi et al. (2019). Participants saw each target sign and its translation individually on a PowerPoint slide and rated the iconicity of each sign on a scale from 1 (not iconic) to 7 (very iconic). The ratings showed that the high ($M = 3.64$, $SD = 1.55$) and low frequency ($M = 3.68$, $SD = 1.76$) signs did not differ in their level of iconicity [$F(1,22) = 0.003$, $p = 0.96$, $\eta^2 = 0.000$].

The iconicity ratings for each target sign are provided in the supplementary materials.[2] An example of a sign rated highly iconic is the sign for ZERO, in which the fingers form a circle. In contrast, an example of a low iconicity sign is the sign for WARM, which is represented by the signer's hand brushing past their chin. Short videos displaying each target sign can be viewed in the supplementary materials: https://osf.io/kf2nr/.

## Sign Recognition Task

The sign recognition task was programmed and administered using PsychoPy 1.85. Its administration took approximately 5 min. Participants viewed 66 short videos of individual signs and indicated by key press whether they had viewed a given sign in the forecast or not. If they thought they had seen the sign, they pressed the 'Yes' key, marked by a sticker on the left arrow button of the keyboard. If they thought they had not seen the sign, they pressed the 'No' key, marked by a sticker on the right arrow button of the keyboard. Signs were presented without any accompanying mouthing and were chosen to generate three different item conditions:

1. *Target items (N = 22)*: signs of STS that had occurred in the weather forecast;
2. *Plausible distractors (N = 22)*: signs of STS that had not occurred in the forecast but were phonologically similar to the target signs; and
3. *Implausible distractors (N = 22)*: signs that had not occurred in the forecast and were not signs of STS. Although they were real signs from other sign languages (in order to ensure ecological validity), they included phonological features that—to the extent of our current knowledge of sign formation—are dispreferred (and therefore rare) within lexical signs across the world's sign languages (Sandler, 2012). This is because they break the formational constraints of selected fingers (for one-handed signs) or the dominance/symmetry constraints (for two-handed signs). As a result, we predicted that participants would not confuse them as readily with the target signs, so would reject them more accurately.

The correct response for Target items was 'Yes', whilst for Plausible and Implausible Distractors it was 'No'. Recall that the target items were further subdivided by their frequency of occurrence in the weather forecast, that is *high frequency items* occurring 8x in the forecast ($N = 11$) and *low frequency items* occurring 3x in the weather forecast ($N = 11$). In addition, target signs were categorised by iconicity, as detailed above. Items with scores above 3.5 were classified as *high iconicity items* ($N = 11$); those with scores of 3.5 or below were considered *low iconicity items* ($N = 11$). The combination of the frequency and iconicity criteria resulted in six high iconicity–high frequency items, six low iconicity–low frequency, five high iconicity–low frequency and five low iconicity–high frequency items.

The experimental task was preceded by four practice trials, after which the instructions were repeated and the first trial began. **Figure 1** summarises the structure of a trial. Participants saw a fixation cross on the screen for 1 s, followed by a stimulus video, the duration of which varied but never exceeded 3 s. After the stimulus video, a question mark appeared on the screen, prompting yes–no responses. Response times were measured from the onset of the video and were not capped, although participants had been instructed to respond as fast as possible to encourage intuitive reactions. Once they had responded, they were taken to the next trial. All items were presented in a different fully randomised order for each participant.

## Individual Differences Battery of Cognitive Tasks

We administered a battery of tasks assessing individual differences which have been implicated in adult language learning, such as cognitive abilities [general executive functions (inhibitory control, phonological working memory), language aptitude, vocabulary size in the first language, and fluid intelligence]. We also assessed executive functions that we expected to impact on sign language learning, namely, visual search abilities, visuo-spatial working memory, and kinaesthetic working memory. All tasks were designed with the aim of generating continuous

[2]https://osf.io/zsrh7/?view_only=fce4401c7284438d94d1ce52c7879733

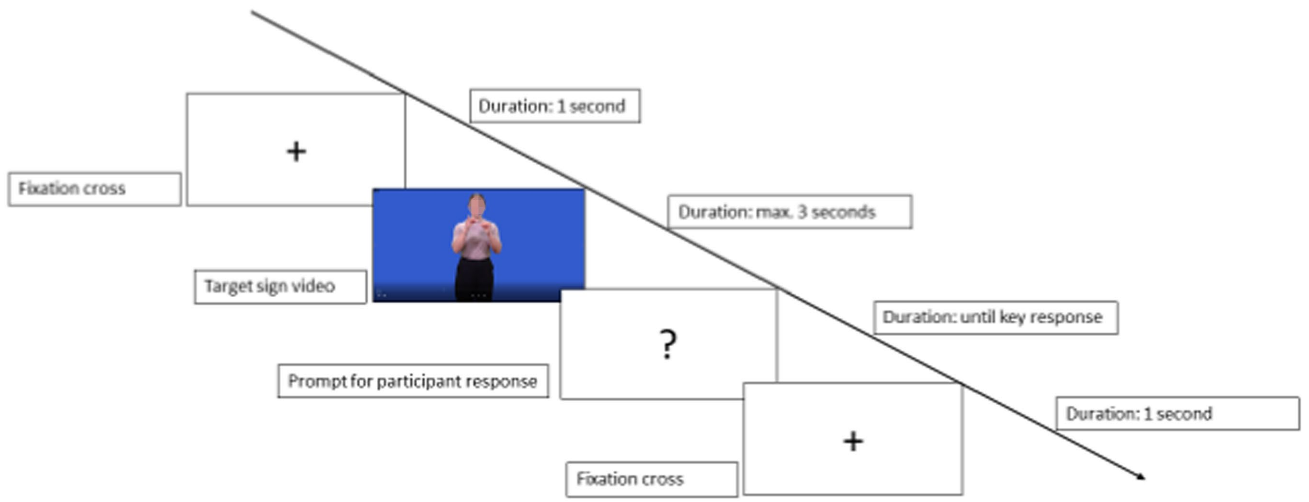


**FIGURE 1** | Structure of a trial in the sign recognition task.

predictor variables suitable for use in linear regression models. The administration duration of each task was approximately 5 min.

## Tasks Assessing Executive Functions

### *Flanker Task*

The Flanker task was based on the high-monitoring version of Eriksen and Eriksen's (1974) Flanker task, as described by Costa et al. (2009), and was created using PsychoPy version 1.8. This task assessed inhibitory control by comparing performance in trials requiring inhibitory control to performance in baseline trials. Participants saw a row of five arrows, presented horizontally. They had to indicate the direction of the central arrow by pressing the left arrow key for a left-facing central arrow and the right arrow key for a right-facing central arrow. In congruent trials, all arrows face the same direction, so no inhibition is required. In incongruent trials, the central target arrow faces a different direction to its surrounding four arrows. To succeed on the task, participants must use inhibitory control to suppress the distractor arrows. In our version of the task, the congruent–incongruent trials were evenly split (48 congruent vs. 48 incongruent). Inhibitory control is measured as the performance difference between incongruent and congruent trials. The task is available at https://osf.io/ub28n/?view_only=fce4401c7284438d94d1ce52c7879733.

### *Visual Search Task*

This task was sourced from the open-access Psytoolkit website https://www.psytoolkit.org/. It assessed individuals' ability to identify a specified target under different conditions of visual search load. Participants saw a display of four versions of the capital letter 'T' (blue T, orange T, upside-down blue T, and upside-down orange T) and were instructed to press the space bar once they had identified the target T, which was defined as the non-inverted orange T. Trials without the target did not require a response. Overall, the task comprised 50 individual trials that differed in visual search load as a function of the number of distractor stimuli present in the display, that is 5, 10, 15, or 20 distractor stimuli. Visual search performance was calculated by comparing RTs in the high load conditions (20 and 15 distractors) with those in the low load conditions (5 and 10 distractors).

### *Visuo-Spatial Working Memory Task*

Visuo-spatial working memory was assessed using the *Corsi forward span*, sourced from the open-access Psytoolkit website https://www.psytoolkit.org/. Participants saw nine pink squares on the laptop screen. In each trial, some of the pink squares light up in yellow in a certain order, and participants are instructed to click on the blocks that have lit up in the order that was shown. The number of blocks gradually rises, increasing the load on visuo-spatial working memory. Participants' Corsi span score is the highest number of squares they memorise at least twice in a row.

### *Phonological Working Memory Task*

We used the version of the *digit forward span* created for the WAIS III test battery (Wechsler, 1997; proprietary material that cannot be shared). Participants listened to pre-recorded sequences of digits, which they had to repeat. The number of digits gradually increased. Participants' phonological working memory score was the raw score of correct responses.

### *Kinaesthetic Working Memory Task*

The design and materials of this task were based on Wu and Coulson (2014), retrieved from https://bclab.ucsd.edu/movementSpanMaterials/. Participants watched short 3-s videos of a series of individual hand and arm movements and were instructed to repeat the movements in the same order. Their replications of the movements were video-recorded. At each span level, the number of movements increased, with each span level comprising two trials. Whilst Wu and Coulson's (2014) task progressed to span level 5, we stopped at span level 3 because piloting had revealed floor effects beyond this span.

Participants' kinaesthetic working memory score was calculated as their raw number of correct responses. When scoring the task, we followed the guidelines provided by Wu and Coulson (2014). Results from a subset of 12 randomly selected participants were scored by two independent judges (first and last authors), whose scores converged highly [$r(1,12) = 0.90$, $p < 0.001$].

### Tasks Assessing Linguistic Skills and Fluid Intelligence

#### *Vocabulary Size in the First Language*

We administered the English vocabulary test of the Wechsler Adult Intelligence Scale WAIS IV (Wechsler et al., 2008; proprietary material that cannot be shared). Participants were presented with 26 English lexical items and asked to provide a definition for each item. Items were presented aurally and visually using PowerPoint slides. Responses were recorded using Audacity and subsequently transcribed and scored based on the detailed WAIS IV scoring manual. To ascertain that the scoring was reliable, the data from a subset of 20 randomly selected participants were scored by two independent judges (first and last authors). This process resulted in an interrater correlation score of $r = 0.94$ at a significance level of $p < 0.001$.

#### *Language Learning Aptitude Tests*

To assess general language aptitude, we administered the Llama B and D sub-sections of the Llama tests (Meara, 2005, as sourced from the Lognostics website in August 2019, https://www.lognostics.co.uk/tools/llama/). LLAMA test scores have been found to correlate with scores in grammaticality judgment tests (Abrahamsson and Hyltenstam, 2008), morphosyntactic attainment (Granena, 2012), collocation knowledge (Granena and Long, 2013), and pronunciation (Granena and Long, 2013). The Llama B test assessed vocabulary learning skills. Participants were presented with 20 images of imaginary animals on the laptop screen. Each animal had a name, which could be revealed by clicking on its screen image. The task consisted in learning as many of the name–stimulus associations as possible within a given time frame of 2 min. Subsequent to this learning phase, participants were tested on their knowledge of the animal names. The Llama D test tapped into implicit phonological language learning. Participants listened to words presented as strings of sound sequences. Subsequently, they were presented with words aurally and asked to make a judgment as to whether or not they had just heard the word. Participants received points for correct responses, but were penalised for incorrect ones.

#### *Fluid Intelligence*

Participants' pattern recognition and logical reasoning ability was assessed using the Matrices component of the Wechsler Adult Intelligence Scale WAIS III (Wechsler, 1997; proprietary material that cannot be shared). This task was completed using pen and pencil. They were presented with sequences of shapes and colours. Each sequence contained a gap. At the bottom of the page, participants encountered five possible shapes that were potential solutions to fill the gap in the sequence. They were asked to select the shape that should logically be used to fill that gap. We used the raw scores based on the total number of correct responses as an indicator of fluid intelligence.

## Analyses

The aim of this study was to investigate the predictors of successful sign recognition on first exposure to minimal input.

The first analysis assessed participants' performance in the different item conditions (targets, plausible distractors, and implausible distractors), thus addressing research questions 1 and 3. We also investigated whether the influence of input factors interacted with the number of times participants had been exposed to the weather forecast, that is the between-subject factor Exposure Group (1x, 2x).

The second analysis focused on the properties of target items, that is research question 2. To investigate the impact of the characteristics of the input materials, the following variables were entered into the mixed models: Frequency of target items (high vs. low) and Iconicity of target items (a continuous variable with a rating scale from 1 = low to 7 = high).

The third analysis explored research question 4, which focused on predictors of accuracy in terms of individual differences between participants.

In all analyses, we used the lme4 and lmer.test package in *R*, which allows for the use of mixed models and automatically provides the results of significance testing in the form of a value of *p* (Kuznetsova et al., 2017). Binary variables were centred using sum-coding by assigning the values −1 and +1, as suggested by Winter (2019). An exception was the analyses comparing accuracy to chance; in these analyses we used the non-centred versions of the fixed effect variables. When taking random effects into consideration, we assumed a maximally conservative approach, allowing both items and subjects to vary by both intercept and slope.

# RESULTS

## Performance Across Item Conditions

The sign recognition task generated a total of 6,138 data points across 93 participants and 66 items. All data points were included in the analyses, except for responses with Reaction times below 150 ms, which were excluded based on the assumption that they represented slips of the finger or premature guesses. **Table 3** displays the average Accuracy rates (Number of correct trials/Number of total trials) for each experimental condition.

To establish differences in accuracy across conditions and how these may have interacted with the number of times participants had viewed the forecast, we created a mixed model using the glmer function (family = 'binomial') with Accuracy (accurate, inaccurate) as the dependent variable and Condition (targets, plausible distractors, and implausible distractors) and Exposure group (1x, 2x) as the predictors. **Table 4** summarises the model output.

As can be seen from **Table 4**, the only significant effect was the variable 'implausible distractors'. However, the *post-hoc* pairwise comparisons using the *emmeans* function in *R* (Winter, 2019) did not reveal any significant differences in accuracy between conditions. All pairwise comparisons were associated with *p* values in excess of 0.2. Crucially, the effect of Exposure group was not significant and accuracy across the three conditions did not interact with Exposure group. Participants who had viewed the weather forecast twice were not more accurate than those who had viewed it once. Hence, Exposure group was not included in our further accuracy analyses. **Figures 2, 3** illustrate these findings by participant and by item.

**TABLE 3 |** Accuracy rates by condition.

| Accuracy rates in % condition | Number of participants | Mean | (*SD*) | Minimum | Maximum |
|---|---|---|---|---|---|
| Targets | 93 | 53 | (14) | 23 | 86 |
| Plausible distractors | 93 | 60 | (14) | 23 | 95 |
| Implausible distractors | 93 | 64 | (15) | 27 | 95 |

**TABLE 4 |** Model output of glmer for accuracy by condition and group.

| **Random effects** | **Variance** | | ***SD*** | |
|---|---|---|---|---|
| Subject | 0.05 | | 0.21 | |
| Item | 0.61 | | 0.78 | |
| **Fixed effects** | ***B*** | ***SE*** | ***Z*** | ***p*** |
| Intercept (targets) | 0.16 | 0.18 | 0.93 | 0.36 |
| Plausible distractors | 0.27 | 0.25 | 1.09 | 0.27 |
| Implausible distractors | 0.50 | 0.25 | 2.00 | 0.045 |
| Group | 0.06 | 0.05 | 1.17 | 0.24 |
| Plausible distractors: group | −0.11 | 0.07 | −1.55 | 0.12 |
| Implausible distractors: group | −0.12 | 0.07 | −1.80 | 0.07 |

*Glmer (accuracy ~ condition*group + (1 + 1|subject) + (1 + 1|item), data, family = 'binomial').*

We subsequently compared recognition performance in the three conditions to chance by constructing a mixed glmer model (family = 'binomial') from which the intercept was removed and the fixed factor Condition was entered in its non-centred version. The dependent variable was Accuracy (accurate, inaccurate), and the predictor variable was Condition (targets, plausible distractors, and implausible distractors). **Table 5** presents the random and fixed effects.

As can be seen from **Table 5**, participants performed at chance on target items. However, on plausible and implausible distractor items they performed significantly above chance. The size of the effect of above-chance performance was greater for the implausible than for the plausible items [Targets: *Cohen's D* = 0.09; Plausible items: *Cohen's D* = 0.26; Implausible items: *Cohen's D* = 0.40, where *Cohen's D* = B/(SQRT(N)*SE)], suggesting that accuracy was greater in the implausible than in the plausible condition. Importantly, a large proportion of variance was explained by random effects due to items (variance = 0.6086). **Figures 2, 3** suggest that this item variability was greatest in the target condition. To explore the effects of items in greater detail, we investigated the impact of iconicity and frequency, which we had predicted would modulate accuracy in the target condition. As can be seen from the random effects, the variance associated with differences between individual participants was only small (variance = 0.0456).

## The Effects of Input Factors on Target Item Recognition

Research question 2 hypothesised that target sign recognition would be modulated by both the frequency and iconicity of each target item. To explore their impact on target item recognition, we conducted a glmer model (family = 'binomial') with Accuracy (accurate, inaccurate) as the dependent variable and Frequency

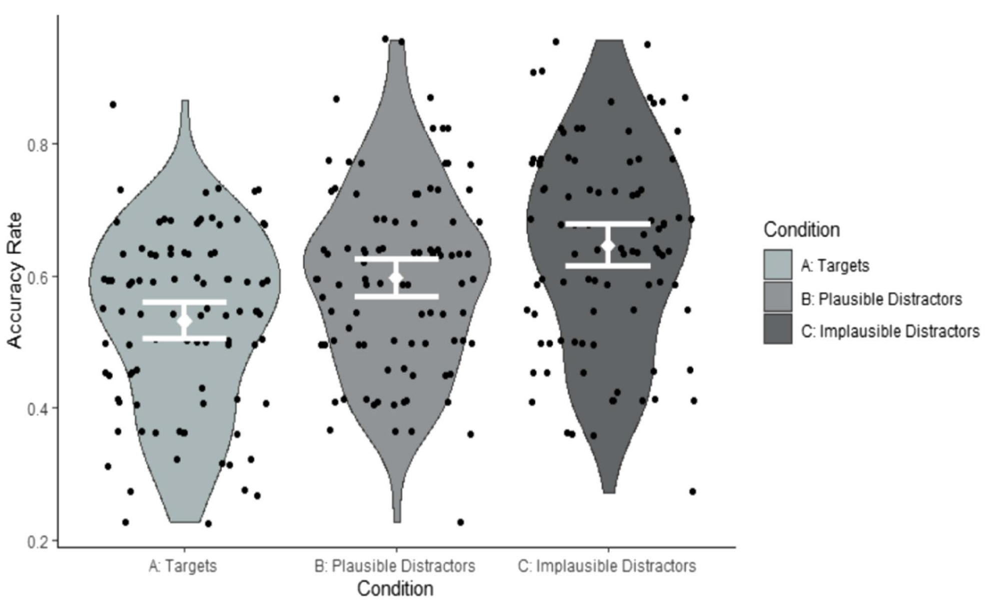


**FIGURE 2 |** Accuracy rates by condition summarised by participants (Correct response Condition A: Yes; Correct response Conditions B and C: No).

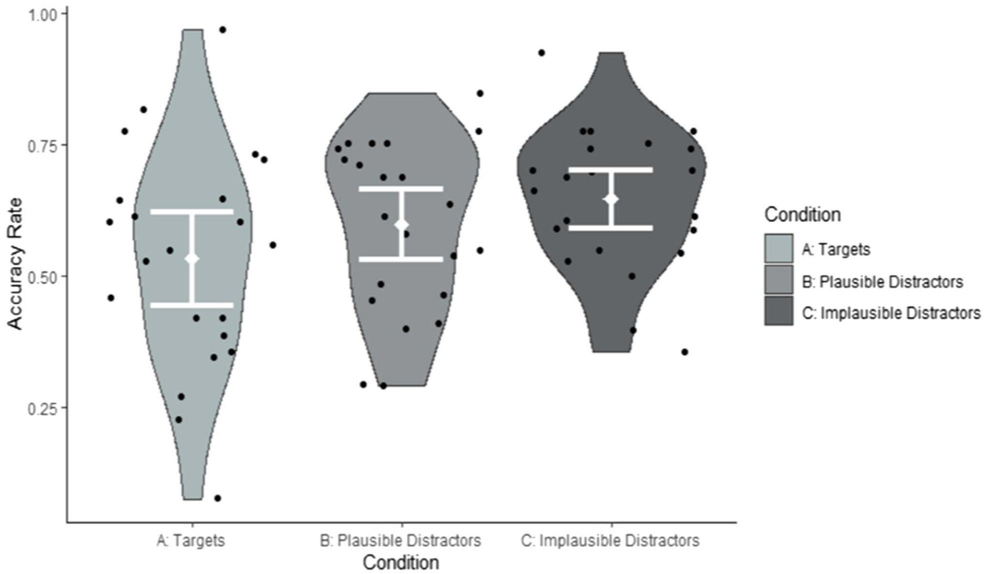


**FIGURE 3 |** Accuracy rates by condition summarised by items (Correct response Condition A: Yes; Correct response Conditions B and C: No).

**TABLE 5 |** Model output for the comparison of accuracy to chance by condition.

| **Random effects** | **Variance** | | ***SD*** | |
|---|---|---|---|---|
| Subject | 0.046 | | 0.21 | |
| Item | 0.61 | | 0.78 | |
| **Fixed effects to chance** | ***B*** | ***SE*** | ***Z*** | ***p*** |
| Targets | 0.16 | 0.18 | 0.90 | 0.37 |
| Plausible distractors | 0.43 | 0.17 | 2.49 | 0.01 |
| Implausible distractors | 0.66 | 0.17 | 3.77 | 0.0002 |

*Glmer (accuracy ~ −1 + condition + (1 + 1|subject) + (1 + 1|item), data, family = 'binomial').*

**TABLE 6 |** Model output accuracy by frequency and iconicity.

| **Random effects** | **Variance** | | ***SD*** | |
|---|---|---|---|---|
| Subject | 0.22 | | 0.47 | |
| Item | 0.74 | | 0.86 | |
| **Fixed effects** | ***B*** | ***SE*** | ***Z*** | ***p*** |
| Intercept | 0.18 | 0.20 | 0.89 | 0.02 |
| Frequency | 0.45 | 0.19 | 2.33 | 0.02 |
| Iconicity | 0.50 | 0.19 | 2.60 | 0.001 |
| Exposure group | 0.07 | 0.07 | 0.95 | 0.34 |
| Frequency: iconicity | 0.11 | 0.19 | 0.57 | 0.57 |
| Frequency: group | 0.05 | 0.05 | 0.97 | 0.33 |
| Iconicity: group | −0.01 | 0.05 | −0.16 | 0.88 |
| Frequency: iconicity: group | −0.01 | 0.05 | −0.20 | 0.84 |

*Glmer (accuracy ~ frequency*iconicity*group + (1 + 1|subject) + (1 + 1|item), data, family = 'binomial').*

(low, high) and Iconicity (continuous ratings on a scale from 1 = 'low' to 7 = 'high') as fixed effects. We also added the between-subject factor Exposure group (1x, 2x) to the analysis. **Table 6** reveals that the fixed effects of both frequency and iconicity were significant, but that there was no interaction between them. This suggests that frequency and iconicity jointly contributed to recognition in a cumulative fashion, as illustrated in **Figures 4–6**. Exposure group was not a significant factor and did not interact with the significant fixed effects.

To further investigate the cumulative effects of frequency and iconicity, as well as possible threshold effects and also to see whether sign recognition relative to chance levels varied as a function of frequency and iconicity, we conducted additional post-hoc analyses. We classified target signs into four categories with four possible frequency–iconicity combinations: (1) items with high frequency and high iconicity, (2) items with high frequency and low iconicity, (3) items with low frequency and high iconicity, and (4) items with low frequency and low iconicity. For the purpose of this grouping, items with iconicity ratings greater than 3.5 were categorised as having 'high iconicity', whilst items with iconicity ratings of 3.5 or less were categorised as having 'low iconicity'. Sign recognition in each of these four frequency–iconicity combinations was then compared to chance. This was achieved with a glmer model by removing the intercept and using the fixed factors in their un-centred format. This analysis revealed that participants only achieved above-chance performance for items that were both highly frequent and highly iconic, that is they only showed clear evidence of recognising items when frequency and iconicity worked in unison. In all other frequency–iconicity combinations, participants performed at chance (see **Table 7**). This suggests a threshold effect: exposure to an item three times did not boost recognition, but exposure to an item 8 times did. However, this facilitative effect depended on items being highly iconic.

## The Effects of Individual Differences on Target Item Recognition Accuracy

Research question 3 probed the potential impact of individual differences between participants on target item recognition. We explored demographic background variables, such as Age

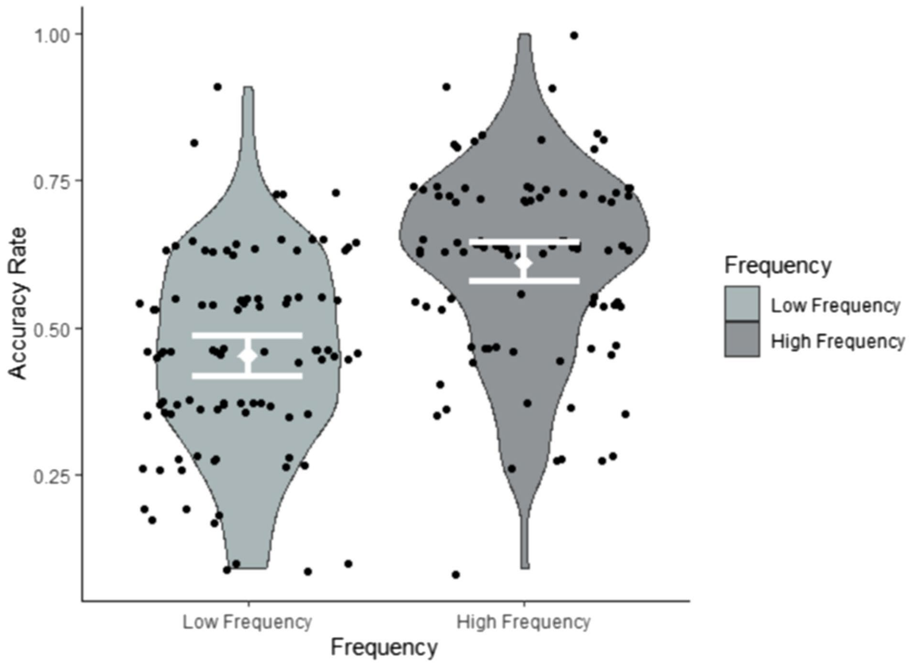


**FIGURE 4 |** Accuracy rates by frequency summarised by participants.

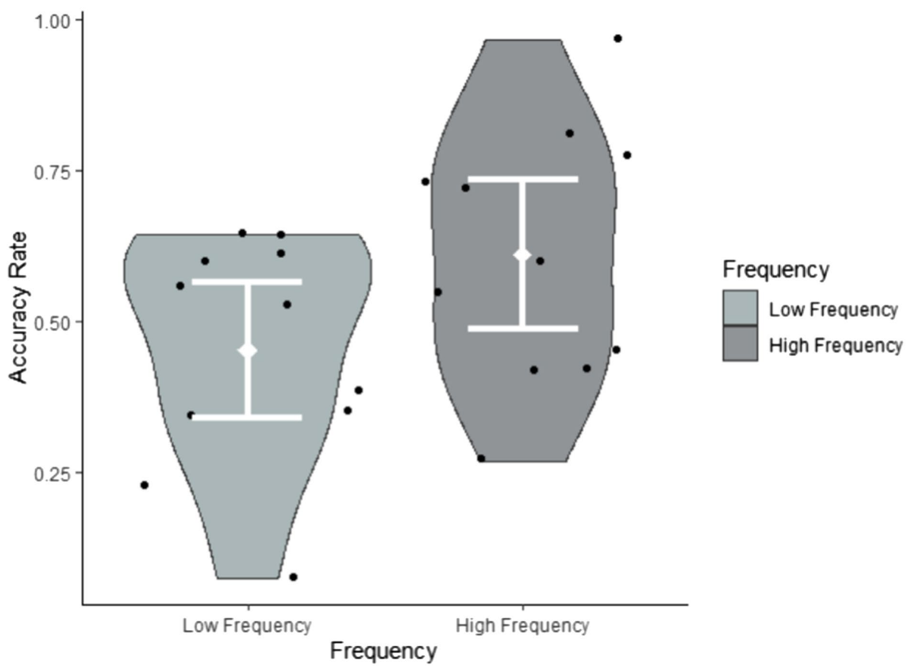


**FIGURE 5 |** Accuracy rates by frequency summarised by items.

and Education, as well as cognitive abilities, such as executive functions, verbal skills, and fluid intelligence. The Flanker task and the Visual Search task produced the effects predicted by the experimental paradigm, confirming that the tasks worked and that participants had understood the instructions. The Flanker task resulted in the Flanker effect (incongruent trial RTs > congruent trial RTs): an ANOVA with Congruency (congruent, incongruent) as the within-subject variable showed that RTs in incongruent trials ($M = 506.41$ ms, $SD = 64.03$ ms) were significantly longer than RTs in congruent trials

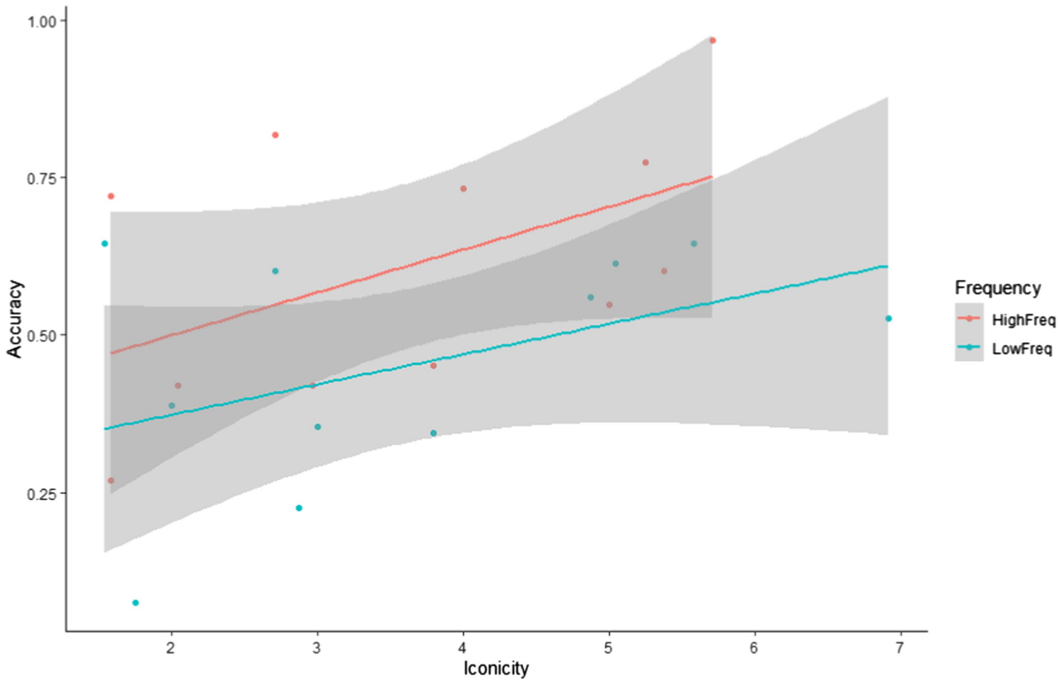


**FIGURE 6** | Correlation between iconicity ratings and accuracy rates by frequency.

**TABLE 7** | Model output for accuracy by chance by frequency and iconicity.

| **Random effects** | | **Variance** | | **SD** |
|---|---|---|---|---|
| Subject | | 0.23 | | 0.48 |
| Item | | 0.83 | | 0.91 |
| **Fixed effects** | ***B*** | ***SE*** | ***Z*** | ***p*** |
| FrequencyHigh-IconicityHigh | 0.98 | 0.39 | 2.51 | 0.01 |
| FrequencyHigh-IconicityLow | 0.16 | 0.42 | 0.38 | 0.71 |
| FrequencyLow IconicityHigh | 0.16 | 0.42 | 0.38 | 0.71 |
| FrequencyLow IconicityLow | −0.63 | 0.39 | −1.63 | 0.10 |

*Glmer (accuracy ~ −1 + frequency:iconicity + (1 + 1|subject) + (1 + 1|item), data, family = 'binomial').*

($M = 445.53$ ms, $SD = 65.39$ ms, $F = 974.37$, $\eta^2 = 0.914$, $p < 0.001$). For the visual search task, an ANOVA revealed the expected Visual Search Load effect, that is longer RTs in displays with 15/20 distractors ($M = 1206.42$ ms, SD = 235.12 ms) than in displays with 10/5 distractors ($M = 993.41$ ms, $SD = 187.74$ ms, $F = 234.16$, $\eta^2 = 0.718$, $p < 0.001$). In addition, we assessed participants' general language learning aptitude, their vocabulary size in their first language (English) and their specific language background and language learning history. The correlational analyses (available at https://osf.io/ub28n/?view_only=fce4401c7284438d94d1ce52c7879733) did not indicate that individual factors were sufficiently strongly interrelated to justify summarising them into latent variables/principal components. Moreover, the correlational analyses did not reveal any significant relationships between the individual differences factors and target item accuracy, which was in line with the low subject-based variability reported by the above-described glmer models. Hence, we did not explore individual predictors further.

## DISCUSSION

The overwhelming experience when encountering a novel spoken language is of being faced with a seemingly impenetrable continuous stream of speech. Learners of sign languages face a comparable hurdle. Our question was whether sign-naïve adults can extract linguistic information after just a few minutes of exposure to a continuous stream of naturalistic signed input in an implicit learning context, as shown previously for spoken language (Gullberg et al., 2010, 2012). Answering this question is an important step towards elucidating those features and skills that are common to all language learning, regardless of modality, and those that are particularly relevant to learning sign languages.

We created a weather forecast in Swedish Sign Language (STS) and hypothesised that sign-naïve participants would be able to distinguish between signs that they had and had not seen in this input when tested immediately afterwards. We found some evidence of this ability. Participants could correctly reject distractors, particularly the implausible distractors, at above-chance levels, although they did not accept target items at above-chance levels. Nevertheless, accuracy of target sign acceptance was modulated by the properties of the signs, as we discuss in more detail below. Contrary to our prediction, however, participants who had watched the forecast twice did not perform more accurately than those who had seen it only once. It is possible that participants paid less attention to the second showing of the video, especially since they were instructed that they would be viewing the same video twice.

In order to better understand what led to more accurate identification of viewed and non-viewed signs, we explored properties of signs themselves. For target signs, we found that frequency and iconicity both impacted on accurate recognition and indeed had a cumulative facilitative effect on target item recognition. Importantly, participants showed clear evidence of above-chance recognition of items that were both highly frequent in the input and highly iconic. The frequency effect matches what has been found for spoken language learning (Ellis, 2012), including in implicit learning contexts (Gullberg et al., 2010, 2012). The effect of iconicity suggests that participants were better at recognising linguistic forms linkable *via* perceptuo-motor analogy to their existing conceptual representations. This in turn suggests that participants were endeavouring to construct meaning as they viewed the forecast, even though meaning *per se* was not tested by the task.

Our findings contribute to a growing body of research indicating that iconicity supports language learning, regardless of modality (Dingemanse et al., 2015; Ortega, 2017). However, given the visual nature of sign languages, iconicity is likely to be particularly salient for learners of sign languages: the visual scope of much of what we communicate about, coupled with the visual nature of the sign modality, means there are many possibilities for direct iconic mappings between form (hand configuration, movement, and location) and meaning (Perniss et al., 2010). The observed effects of iconicity could be investigated further by drawing upon the distinction between the notions of *iconicity* and *transparency* (Sevcikova Sehyr and Emmorey, 2019). Iconicity describes a recognisable similarity between a sign and its meaning when participants are provided with both the sign and its meaning. Transparency refers to signs to which the correct meaning can be unambiguously assigned without explicitly being given the meaning. It is likely that the signs on which participants performed above-chance level in this study would also be classified as highly transparent. Future research on incidental sign language learning should go into further detail on this matter because transparency might be particularly relevant for meaning assignment in implicit learning contexts.

We predicted that differential performance on phonologically plausible and implausible distractor items would provide insights into how much phonological information about STS participants had extracted. The data indicated that participants were more accurate at correctly rejecting implausible signs than at correctly rejecting plausible signs, suggesting that they recognised some of the phonological properties that are not part of STS. Two possible explanations can be postulated: first, participants actually built some knowledge of STS phonology during the brief exposure, as learners have been shown to do at first implicit exposure of spoken language (e.g., Ristin-Kaufmann and Gullberg, 2014); second, participants drew on their knowledge of gestural movements and related motor schemas in their assessment of what constitutes plausible manual signs, a knowledge that may go beyond just the particular sign language (STS) viewed in our study. Support for this latter view comes from studies showing that gestures can serve as a substrate for sign language learning (e.g., Marshall and Morgan, 2015; Boers-Visker, 2021). Hence, the differences between phonologically plausible and implausible items might have arisen from sensitivity to articulatory ease (from knowledge of either human biomechanics or gesture), rather than from extracting phonological information from the input.

Finally, we predicted that the accuracy with which participants recognised target signs would be modulated by individual differences in their cognitive skills and existing knowledge of spoken languages. Surprisingly, we found no support for this prediction. However, given that mean performance was at chance for some target items, we acknowledge that only limited observations can be made about the correlation between these factors and actual learning. Nevertheless, the absence of correlations between individual differences and performance accuracy raises the question whether implicit learning in first-exposure contexts is modulated by the individual-level factors we assessed. In explicit sign learning studies, there is mixed evidence for an influence of individual language and cognitive differences on initial learning (Williams et al., 2017; Martinez and Singleton, 2018, 2019). Meanwhile, there is considerable debate over the role of individual differences in implicit spoken language learning (Williams, 2009). An important question remains as to when in the learning trajectory, and under what conditions, the individual's cognitive and linguistic makeup starts to matter.

This preliminary investigation into sign language learning at first exposure opens many avenues for further research. Importantly, we had no post-test to assess whether the recognition effect translated into a longer-term memorisation of sign forms, which is clearly an important step in lexical learning. Furthermore, the effect of iconicity on sign recognition suggests that participants may have engaged in some form of meaning assignment, although the task itself did not test this. Future research should investigate whether sign-naïve participants, in such an implicit learning context, make links between sign forms and their meanings, similar to spoken language findings of Gullberg et al. (2010). Meanwhile, our participants' relative success at identifying the phonologically implausible distractor signs as not having been present in the forecast suggests that learners might extract information about the phonological properties of the target sign language at first exposure. This should be explored further, potentially by adapting the lexical decision task of Gullberg et al. (2010). Finally, for practical reasons we studied the learning of just one sign language (i.e., STS), by native speakers of the same language (i.e., English), with just one set of input materials. Our study therefore needs replicating in different sign languages, in adults with different spoken languages and with input materials other than a weather forecast, in order to determine the extent to which our findings hold across languages, populations, and contexts.

In conclusion, our results suggest that during only 4 min of naturalistic continuous language input in a new modality, the adult language learning mechanism can extract information about linguistic forms. Adults can detect individual signs in a continuous sign-stream, create memory traces for (some of) them and extract information about phonology. Crucially, input properties may matter more for implicit learning at this initial stage than learner characteristics. Moreover, we observed both modality-general and modality-relevant effects: the adult mechanism for language learning operates similarly on signed and spoken languages as regards frequency, but also exploits modality-salient properties, such as iconicity for signed languages. Our data suggest that despite the considerable learning challenges, adults have powerful learning mechanisms that enable them to make that first important break into a language—even when visual—to recognise word forms and glean linguistic information from unfamiliar linguistic input.

## DATA AVAILABILITY STATEMENT

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found at: https://osf.io/ub28n/?view_only=fce4401c7284438d94d1ce52c7879733.

## ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Institute of Education Staff Research Ethics Committee, University College London, London, United Kingdom. The patients/participants provided their written informed consent to participate in this study.

## AUTHOR CONTRIBUTIONS

JH, LA, VJ, MG, and CM contributed to the design of the study and provided critical revisions. JH, LA, and CM collected the data. JH organised the database and conducted the statistical analyses. JH, MG, and CM wrote the first draft of the paper. All authors contributed to the article and approved the submitted version.

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## REFERENCES

Abrahamsson, N., and Hyltenstam, K. (2008). The robustness of aptitude effects in near-native second language acquisition. *Stud. Second. Lang. Acquis.* 30, 481–509. doi: 10.1017/S027226310808073X

Artieda, G., and Muñoz, C. (2016). The LLAMA tests and the underlying structure of language aptitude at two levels of foreign language proficiency. *Learn. Individ. Differ.* 50, 42–48. doi: 10.1016/j.lindif.2016.06.023

Baddeley, A. D. (2017). Modularity, working memory and language acquisition. *Second. Lang. Res.* 33, 299–311. doi: 10.1177/0267658317709852

Birdsong, D. (2005). "Interpreting age effects in second language acquisition," in *Handbook of Bilingualism: Psycholinguistic Approaches*. eds. J. Kroll and A. De Groot (Oxford: Oxford University Press), 109–127.

Boers-Visker, E. (2021). Learning to use space – a study into the SL2 acquisition process of adult learners of sign language of the Netherlands. [Doctoral Thesis, The Netherlands Graduate School of Linguistics], Amsterdam. Available at: https://lotschool.nl/lot-569-learning-to-use-space/ (Accessed March 25, 2022).

Christiansen, M. H. (2019). Implicit statistical learning: a tale of two literatures. *Top. Cogn. Sci.* 11, 468–481. doi: 10.1111/tops.12332

Costa, A., Hernández, M., Costa-Faidella, J., and Sebastián-Gallés, N. (2009). On the bilingual advantage in conflict processing: now you see it, now you don't. *Cognition* 113, 135–149. doi: 10.1016/j.cognition.2009.08.001

De Diego Balaguer, R., Toro, J., Rodriguez-Fornells, A., and Bachoud-Lévi, A. C. (2007). Different neurophysiological mechanisms underlying word and rule extraction from speech. *PLoS One* 2:e1175. doi: 10.1371/journal.pone.0001175

DeKeyser, R. (2003). "Explicit and implicit learning," in *The Handbook of Second Language Acquisition*. eds. C. Doughty and M. H. Long (Oxford: Blackwell Publishing Limited), 313–348.

Dimroth, C., Rast, R., Starren, M., and Watorek, M. (2013). Methods for studying a new language under controlled input conditions: The VILLA project. *EUROSLA Yearb.* 13, 109–138. doi: 10.1075/eurosla.13.07dim

Dingemanse, M., Blasi, D., Lupyan, G., Christiansen, M., and Monaghan, P. (2015). Arbitrariness, iconicity and systematicity in language. *Trends Cogn. Sci.* 19, 604–615. doi: 10.1016/j.tics.2015.07.013

Dörnyei, Z., and Ryan, S. (2015). *The Psychology of the Language Learner—Revisited.* New York and London: Routledge.

Ellis, N. (2012). "What can we count in language, and what counts in language acquisition, cognition, and use?" in *Frequency Effects in Language Learning and Processing. Vol. 1*. eds. S. T. Gries and D. Divjak (Mouton de Gruyter), 7–34.

Ellis, N., and Collins, L. (2009). Input and second language acquisition: the roles of frequency, form, and function. Introduction to the special issue. *Mod. Lang. J.* 93, 329–335. doi: 10.1111/j.1540-4781.2009.00893.x

Ellis, N., Römer, U., and O'Donnell, M. (2016). *Usage-Based Approaches to Language Acquisition and Processing: Cognitive and Corpus Investigations of Construction Grammar.* Malden, MA: Wiley.

Ellis, N., and Wulff, S. (2020). "Usage-based approaches to second language acquisition. Chapter 4," in *Theories in Second Language Acquisition: An Introduction. 3rd Edn*. eds. B. VanPatten, G. Keating and S. Wulff (New York and London: Routledge). 63–82.

Eriksen, B. A., and Eriksen, C. W. (1974). Effects of noise letters upon identification of a target letter in a non-search task. *Percept. Psychophys.* 16, 143–149. doi: 10.3758/BF03203267

Gomez, R. L., and Gerken, L. (1999). Artificial grammar learning by 1-year-olds leads to specific and abstract knowledge. *Cognition* 70, 109–135. doi: 10.1016/S0010-0277(99)00003-7

Granena, G. (2012). Age Differences and Cognitive Aptitudes for Implicit and Explicit Learning in Ultimate Second Language Attainment. Doctoral dissertation. Berlin: University of Maryland.

Granena, G., Jackson, D. O., and Yilmaz, Y. (2016). *Cognitive in Second Language Processing and Acquisition. Vol. 3.* Amsterdam: John Benjamins Publishing Company.

Granena, G., and Long, M. H. (2013). Age of onset, length of residence, language aptitude, and ultimate L2 attainment in three linguistic domains. *Second. Lang. Res.* 29, 311–343. doi: 10.1177/0267658312461497

Grey, S. (2020). What can artificial languages reveal about morphosyntactic processing in bilinguals? *Biling. Lang. Congn.* 23, 81–86. doi: 10.1017/S1366728919000567

Gullberg, M. (2022). "Bimodal convergence: How languages interact in multicompetent language users' speech and gestures," in *Gesture in Language: Development Across the Lifespan*. eds. A. Morgenstern and S. Goldin-Meadow (Berlin: Mouton de Gruyter), 317–333.

Gullberg, M., Roberts, L., and Dimroth, C. (2012). What word-level knowledge can adult learners acquire after minimal exposure to a new language? *Int. Rev. Appl. Linguist. Lang. Teach.* 50, 239–276. doi: 10.1515/iral-2012-0010

Gullberg, M., Roberts, L., Dimroth, C., Veroude, K., and Indefrey, P. (2010). Adult language learning after minimal exposure to an unknown natural language. *Lang. Learn.* 60, 5–24. doi: 10.1111/j.1467-9922.2010.00598.x

Hayakawa, S., Ning, S., and Marian, V. (2020). From Klingon to Colbertian: using artificial languages to study word learning. *Biling. Lang. Cogn.* 23, 74–80. doi: 10.1017/S1366728919000592

Hofweber, J., Marinis, T., and Treffers-Daller, J. (2020). How different code-switching types modulate bilinguals' executive functions—a dual control mode perspective. *Biling. Lang. Congn.* 23, 909–925. doi: 10.1017/S1366728919000804

Hommel, B., Li, K. Z., and Li, S. C. (2004). Visual search across the life span. *Dev. Psychol.* 40, 545–558. doi: 10.1037/0012-1649.40.4.545

Horst, M., Cobb, T., and Meara, P. (1998). Beyond a clockwork orange: acquiring second language vocabulary through reading. *Read. Foreign Lang.* 11, 207–223.

Hulstijn, J. H. (2003). "Incidental and intentional learning," in *The Handbook of Second Language Acquisition*. eds. C. J. Doughty and M. H. Long (Oxford: Blackwell Publishing Limited), 349–381.

Janke, V., and Marshall, C. R. (2017). Using the hands to represent objects in space: Gesture as a substrate for signed language acquisition. *Front. Psychol.* 8:2007. doi: 10.3389/fpsyg.2017.02007

Klein, W. (1986). Second language acquisition. Cambridge: Cambridge University Press).

Kittleson, M. M., Aguilar, J. M., Tokerud, G. L., Plante, E., and Asbjørnsen, A. E. (2010). Implicit language learning: adults' ability to segment words in Norwegian. *Biling. Lang. Congn.* 13, 513–523. doi: 10.1017/S1366728910000039

Kuznetsova, A., Brockhoff, P. B., and Christensen, R. B. H. (2017). lmerTest package: tests in linear mixed effects models. *J. Stat. Softw.* 82, 1–26. doi: 10.18637/jss.v082.i13

Li, S. (2018). "Language aptitude," in *Cambridge Guide to Learning English as a Second Language*. eds. A. Burns and J. Richards (Cambridge: Cambridge University Press), 63–72.

Li, P., Zhang, F., Tsai, E., and Puls, B. (2014). Language history questionnaire (LHQ 2.0): a new dynamic web-based research tool. *Biling. Lang. Congn.* 17, 673–680. doi: 10.1017/S1366728913000606

Luk, G., and Bialystok, E. (2013). Bilingualism is not a categorical variable: interaction between language proficiency and usage. *J. Cogn. Psychol.* 25, 605–621. doi: 10.1080/20445911.2013.795574

Marshall, C. R., and Morgan, G. (2015). From gesture to sign language: conventionalisation of classifier constructions by adult hearing learners of BSL. *Top. Cogn. Sci.* 7, 61–80. doi: 10.1111/tops.12118

Martinez, D., and Singleton, J. L. (2018). Predicting sign learning in hearing adults: The role of perceptual-motor (and phonological?) processing. *Appl. Psycholinguist.* 39, 905–931. doi: 10.1017/S0142716418000048

Martinez, D., and Singleton, J. L. (2019). The effect of bilingualism on lexical learning and memory across two language modalities: some evidence for a domain-specific, but not general, advantage. *J. Cogn. Psychol.* 31, 559–581. doi: 10.1080/20445911.2019.1634080

Maye, J., Werker, J. F., and Gerken, L. (2002). Infant sensitivity to distributional information can affect phonetic discrimination. *Cognition* 82, B101–B111. doi: 10.1016/S0010-0277(01)00157-3

Meara, P. M. (2005). *Llama Language Aptitude Tests*. Swansea: Lognostics.

Moore Mauroux, S. (2016). Patterns and variation in the weather forecast: can prosodic features be predicted too? *Anglophonia* 21:755. doi: 10.4000/anglophonia.755

Morgan-Short, K. (2020). Insights into the neural mechanisms of becoming bilingual: a brief synthesis of second language research with artificial linguistic systems. *Biling. Lang. Cogn.* 23, 87–91. doi: 10.1017/S1366728919000701

Motamedi, Y., Little, H., Nielsen, A., and Sulik, J. (2019). The iconicity toolbox: empirical approaches to measuring iconicity. *Lang. Cogn.* 11, 188–207. doi: 10.1017/langcog.2019.14

O'Brien, I., Segalowitz, N., Freed, B., and Collentine, J. (2007). Phonological memory predicts second language oral fluency gains in adults. *Stud. Second. Lang. Acquis.* 29, 557–581. doi: 10.1017/S027226310707043X

Orfanidou, E., Adam, R., Morgan, G., and McQueen, J. (2010). Recognition of signed and spoken language: different sensory inputs, the same segmentation procedure. *J. Mem. Lang.* 62, 272–283. doi: 10.1016/j.jml.2009.12.001

Orfanidou, E., McQueen, J., Adam, R., and Morgan, G. (2015). Segmentation of British sign language (BSL): mind the gap! *Q. J. Exp. Psychol.* 68, 641–663. doi: 10.1080/17470218.2014.945467

Ortega, G. (2017). Iconicity and sign language acquisition: a review. *Front. Psychol.* 8:1280. doi: 10.3389/fpsyg.2017.01280

Ortega, G., Schieffner, A., and Özyürek, A. (2019). Hearing non-signers use their gestures to predict iconic form-meaning mappings at first exposure to signs. *Cognition* 191:103996. doi: 10.1016/j.cognition.2019.06.008

Paradis, J. (2011). Individual differences in child English second language acquisition: comparing child-internal and child-external factors. *Linguist. Approach. Bilingual.* 1, 213–237. doi: 10.1075/lab.1.3.01par

Pellicer-Sánchez, A. (2016). Incidental L2 vocabulary acquisition from and while reading: an eye-tracking study. *Stud. Second. Lang. Acquis.* 38, 97–130. doi: 10.1017/S0272263115000224

Perdue, C. (ed.) (1993). *Adult Language Acquisition: Cross-Linguistic Perspectives. Vol. I: Field Methods; Vol. II: The Results*. Cambridge: Cambridge University Press.

Perniss, P., Thompson, R. L., and Vigliocco, G. (2010). Iconicity as a general property of language: evidence from spoken and signed languages. *Front. Psychol.* 1:227. doi: 10.3389/fpsyg.2010.00227

Peters, E., and Webb, S. (2018). Incidental vocabulary acquisition through viewing L2 television and factors that affect learning. *Stud. Second. Lang. Acquis.* 40, 551–577. doi: 10.1017/S0272263117000407

Pigada, M., and Schmitt, N. (2006). Vocabulary acquisition from extensive reading: a case study. *Read. Foreign Lang.* 18, 1–28. doi: 10.4236/ojml.2015.53023

Rast, R. (2008). *Foreign Language Input: Initial Processing.* Clevedon: Multilingual Matters.

Rebuschat, P., Monaghan, P., and Schoetensack, C. (2021). Learning vocabulary and grammar from cross-situational statistics. *Cognition* 206:104475. doi: 10.1016/j.cognition.2020.104475

Rebuschat, P., and Williams, J. N. (eds.) (2012). "Introduction: statistical learning and language acquisition," in *Statistical Learning and Language Acquisition*. Berlin: Mouton de Gruyter, 1–12.

Ristin-Kaufmann, N., and Gullberg, M. (2014). The effects of first exposure to an unknown language at different ages. *Bull. Suisse de Linguistique Appl.* 99, 17–29.

Robinson, P. (2001). Individual differences, cognitive abilities, aptitude complexes and learning conditions in second language acquisition. *Second. Lang. Res.* 17, 368–392. doi: 10.1177/026765830101700405

Robinson, P. (2005). Cognitive abilities, chunk-strength and frequency effects in implicit artificial grammar and incidental second language learning: replications of Reber, Walkenfeld, and Hernstadt (1991) and Knowlton and squire (1996) and their relevance for SLA. *Stud. Second. Lang. Acquis.* 27, 235–268. doi: 10.1017/S0272263105050126

Rodgers, M., and Webb, S. (2020). Incidental vocabulary learning through viewing television. *Int. J. Appl. Linguist.* 171, 191–220. doi: 10.1075/itl.18034.rod

Saffran, J. R., Aslin, R. N., and Newport, E. L. (1996). Statistical learning by 8-month-old infants. *Science* 274, 1926–1928. doi: 10.1126/science.274.5294.1926

Saffran, J. R., Newport, E. L., Aslin, R. N., Tunick, R. A., and Barrueco, S. (1997). Incidental language learning: listening (and learning) out of the corner of your ear. *Psychol. Sci.* 8, 101–105. doi: 10.1111/j.1467-9280.1997.tb00690.x

Sandler, W. (2012). The phonological organization of sign languages. *Lang Ling Compass* 6, 162–182. doi: 10.1002/lnc3.326

Sevcikova Sehyr, Z., and Emmorey, K. (2019). The perceived mapping between form and meaning in American sign language depends on linguistic knowledge and task: evidence from iconicity and transparency judgments. *Lang. Cogn.* 11, 208–234. doi: 10.1017/langcog.2019.18

Singleton, D., and Pfenninger, S. E. (2018). "The age debate: a critical overview," in *The Routledge Handbook of Teaching English to Young Learners*. eds. S. Garton and F. Copland (London: Routledge), 30–43.

Veroude, K., Norris, G., Shumskaya, E., Gullberg, M., and Indefrey, P. (2010). Functional connectivity between brain regions involved in learning words of a new language. *Brain Lang.* 113, 21–27. doi: 10.1016/j.bandl.2009.12.005

Waring, R., and Takaki, M. (2003). At what rate do learners learn and retain new vocabulary from reading a graded reader? *Read. Foreign Lang.* 15, 130–163.

Webb, S. (2005). Receptive and productive vocabulary learning: the effect of reading and writing on word knowledge. *Stud. Second. Lang. Acquis.* 27, 33–52. doi: 10.1017/S0272263105050023

Wechsler, D. (1997). *WAIS-III Administration and Scoring Manual.* San Antonio, TX: The Psychological Corporation.

Wechsler, D., Coalson, D. L., and Raiford, S. E. (2008). *WAIS-IV Technical and Interpretive Manual.* San Antonio: Pearson.

Wen, Z., and Li, S. (2019). "Working memory in L2 learning and processing," in *The Cambridge Handbook of Language Learning*. eds. J. Schwieter and A. Benati (Cambridge: Cambridge University Press), 365–389.

Williams, J. N. (2009). "Implicit learning in second language acquisition," in *The New Handbook of Second Language Acquisition*. eds. W. C. Ritchie and T. K. Bhatia (Bingley: Emerald), 319–353.

Williams, J. T., Darcy, I., and Newman, S. D. (2017). The beneficial role of L1 spoken language skills on initial L2 sign language learning: cognitive and linguistic predictors of M2L2 acquisition. *Stud. Second. Lang. Acquis.* 39, 833–850. doi: 10.1017/S0272263116000322

Williams, J. N., and Rebuschat, P. (eds.) (2012). "Statistical learning and syntax: what can be learned, and what difference does meaning make?" in *Statistical Learning and Language Acquisition*. Boston: De Gruyter Mouton, 237–264.

Winter, B. (2019). *Statistics for Linguists: An Introduction Using R.* New York and London: Routledge.

Wu, Y. C., and Coulson, S. (2014). A psychometric measure of working memory capacity for configured body movement. *PLoS One* 9:e84834. doi: 10.1371/journal.pone.0084834

Yu, C., and Smith, L. B. (2007). Rapid word learning under uncertainty via cross-situational statistics. *Psychol. Sci.* 18, 414–420. doi: 10.1111/j.1467-9280.2007.01915.x

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# Effects of Age-of-Acquisition on Proficiency in Polish Sign Language: Insights to the Critical Period Hypothesis

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This study focuses on the relationship between the age of acquisition of Polish Sign Language (PJM) by deaf individuals and their receptive language skills at the phonological, morphological and syntactic levels. Sixty Deaf signers of PJM were recruited into three equal groups ($n = 20$): (1) a group exposed to PJM from birth from their deaf parents; (2) a group of childhood learners of PJM, who reported learning PJM between 4 and 8 years; (3) a group of adolescent learners of PJM, who reported learning PJM between 9 and 13 years. The PJM Perception and Comprehension Test was used to assess three aspects of language processing: phonological, morphological and syntactic. Participants were asked to decide whether a series of signs and sentences were acceptable in PJM. Results show that the age of PJM acquisition has a significant impact on performance on this task. The earlier deaf people acquire PJM, the more likely they were to distinguish signs and sentences considered permissible and impermissible in PJM by native signers. Native signers had significantly greater accuracy on the phonological, morphological, and syntactic items than either the Childhood or the Adolescent signers. Further, the Childhood signers had significantly greater accuracy than the Adolescent signers on all three parts of the test. Comparing performance on specific structures targeted within each part of the test revealed that multi-channel signs and negative suffixes posed the greatest challenge for Adolescent signers relative to the Native signers. The above results provide evidence from a less-commonly studied signed language that the age of onset of first language acquisition affects ultimate outcomes in language acquisition across all levels of grammatical structure. In addition, this research corroborates prior studies demonstrating that the critical period is independent of language modality. Contrary to a common public health assumption that early exposure to language is less vital to signed than to spoken language development, the results of this study demonstrate that early exposure to a signed language promotes sensitivity to phonological, morphological and syntactic patterns in language.

**Keywords: age of acquisition (AoA), signed language, deaf, Polish Sign Language (PJM), critical period for language (CPL), language acquisition, language input**

## INTRODUCTION

In this article, we address a pressing need: deaf infants need accessible language input from birth. The evidence we present in support of this claim comes from a comparison of responses to Polish Sign Language (PJM) stimuli by deaf adults who were first exposed to a signed language at birth, or in early childhood, or in adolescence. We will show that individuals who begin to acquire language earlier in life develop stronger expectations about language use. All of the participants of our research are active and valued members of their communities and use PJM every day. All of the participants can also successfully negotiate a variety of communicative contexts using their linguistic knowledge. We will focus on some differences in the language usage of the participants that are tied to the age of first exposure to language. These differences have sometimes been presented in the literature on signed language acquisition as disorders. As Henner and Robinson (2021) have noted, linguists contribute to deficit perspectives on language varieties and language users by labeling less typical patterns of language use as disordered. Importantly, differences in language usage are often adaptations to environmental conditions beyond the control of the individual language users. This is certainly the case in the present study. Participants who were not exposed to language in early life had no way to influence their access to accessible language input. Studying their use of language provides important insights to scientific questions such as whether or not there is a Critical Period for Language (CPL).

Interest in the CPL has persisted for decades despite conflicting evidence for boundary conditions on language acquisition, inconsistencies in ultimate attainment in second language learners, and disagreement about the specific neurological systems underlying language processing. Mayberry and Kluender (2018) summarize the evidence on this issue, and argue that one barrier to a consensus on the CPL is the conflation of evidence from first and second language acquisition. Cases of first language acquisition beginning later than birth are rare, but are essential for our understanding of the CPL. These studies focus on deaf individuals who grew up in hearing families who used only spoken language at home. In many such cases, language acquisition was delayed until the deaf person had access to a signed language in a pre-school or school setting. Evidence from such cases has shown notable differences in linguistic performance and in the organization of neural systems supporting language processing when comparing signers exposed to language from birth to those who first started acquiring a language in adolescence. But almost all cases come from signers of a single language – American Sign Language (ASL) – with a handful of studies on signers of British Sign Language (BSL).

One of the earliest attempts to test the CPL by investigating language processing abilities in deaf individuals was carried out by Mayberry and Fischer (1989). Psycholinguistic investigations of signed languages were still in their infancy, and an exciting discovery at the time was the ability to distinguish form and meaning processing through experimental tasks (Bellugi et al., 1975; Siple et al., 1977). Mayberry and Fischer (1989) carried out two studies in which they asked deaf adults to watch signed narratives, sentences, and agrammatical sequences of signs. Participants either shadowed the signs as they watched them or recalled the stimulus sentences after they were complete. Subsequently, they responded to comprehension questions about the signed stimuli. In some cases, visual noise was added to the signed stimuli to increase task difficulty. Across all conditions in both studies, age of first language acquisition was a strong predictor of performance. The pattern that emerged from the two initial studies and that has since been replicated with additional controls and alternative protocols (Mayberry and Eichen, 1991; Mayberry, 1993; Emmorey et al., 1995b; Morford and Carlson, 2011; Hauser et al., 2016; Woll, 2018; Schönström and Hauser, 2022), is that earlier acquisition is associated with rapid and efficient processing of phonological form in order to access and store linguistic meaning. In Mayberry and Fischer's studies, native signers deleted or substituted signs during shadowing and recall, but in a manner that preserved the meaning of the stimulus sentences. By contrast, the later first language learning began, the more likely signers were to show evidence of shallow processing of the stimuli. Late learners substituted target signs with phonologically similar signs that did not retain the meaning of the stimulus sentences, and they produced sequences of signs that were agrammatical or semantically incoherent in ASL. Participants whose errors pointed to a focus on the form of the signs, but not their meaning, showed much lower rates of comprehension of the stimuli as well.

Subsequent studies have explored age-of-acquisition effects by probing the sensitivity of signers exposed to a first language at different ages on grammaticality judgment tasks. Boudreault and Mayberry (2006) asked participants to distinguish between grammatical and agrammatical versions of ASL sentences that varied in grammatical complexity. They found a significant effect of age of acquisition on accuracy. The later participants had acquired ASL, the more likely they were to find agrammatical sentences acceptable. Further, the error rate increased for more complex structures. Accuracy was highest in simple sentences with uninflected verbs and sentences incorporating negation, and lowest for relative clauses. For a subset of the experimental stimuli, the grammatical structure could be marked by either manual or non-manual signs. For example, negation can be expressed with a sign such as NOT or with a non-manual headshake with scope over the predicate to be negated. Although the investigators did not find evidence for an effect of age of acquisition on sensitivity to manual vs. non-manual grammatical marking, all participants made more errors on grammatically complex sentences with non-manual markers than those with manual markers. The effects of age-of-acquisition on grammaticality judgments were partially replicated in a study of native and childhood BSL signers (Cormier et al., 2012), but conflicting results are reported by Krebs et al. (2021) who were not able to find robust age-of-acquisition effects on grammaticality judgments in Austrian Sign Language for a subset of the grammatical structures investigated by Boudreault and Mayberry (2006).

Evidence that grammatical production is also impacted by age of first language acquisition comes from an elicited production task with highly experienced signers who were first exposed to ASL at different ages. Newport (1990) found that signers who started acquiring ASL later in life were more likely to omit obligatory grammatical verb marking or to replace multimorphemic verbal predicates with sequences of monomorphemic signs. A longitudinal study of two teenagers who were ages 12;1 and 13;7 when first exposed to ASL documented gradual and consistent progress in the acquisition of ASL verb agreement and classifier predicates over the first 3 years of acquisition (Morford, 2003). The deaf signers in Morford's study did not produce comparable errors to those reported by Newport (1990), but they were observed in naturalistic interaction and completing a story retelling task instead of under experimental laboratory conditions. In order to probe possible disruptions to language processing, the participants in Morford's study were asked to complete a sentence to picture matching task and a sentence repetition task. On these more controlled tasks, difficulties in language processing were apparent. Interestingly, when given the opportunity to watch the stimuli at a slower rate and to watch them multiple times, performance improved. Emmorey et al. (1995a) similarly report superior performance on offline compared to online grammatical processing in non-native signers. Improvement in performance of late learners of language when the time constraints are eased suggests that these individuals, like those described by Mayberry and Fischer (1989) and Mayberry and Eichen (1991), were struggling to access meaning from the signed forms in an efficient manner.

Given these patterns of language processing difficulties, some investigators have asked whether and how phonological processing is impacted by delayed first language exposure. For example, is perception of phonological parameters similar in native and non-native signers? Two studies have compared handshape perception in native and adolescent first language signers and report higher rates of handshape discrimination in adolescent learners than in native signers (Morford et al., 2008; Best et al., 2010). Moreover, Morford and Carlson (2011) compared signers on a handshape and location monitoring task, and found that adolescent first language signers were significantly more accurate than hearing L2 signers, and marginally more accurate than native signers, particularly for the handshape trials. The adolescent signers were also the only group to show faster responses to handshape targets than to location targets. Finally, Hildebrandt and Corina (2002) report differences in phonological similarity judgments across native and adolescent signers. While the former judge signs overlapping in movement to be most similar, the latter were more likely to judge signs overlapping in handshape to be most similar.

Although it is rare to find superior performance on a language processing task in adolescent first language learners, the pattern of performance on phonological processing tasks – even including superior performance – is consistent with the argument that one effect of delayed exposure to language is an increased allocation of attentional resources to linguistic form since lexical access is less automated (Mayberry and Fischer, 1989; Mayberry, 1995; Morford and Mayberry, 2000; Mayberry and Kluender, 2018). Morford and Carlson (2011) propose that adolescent signers may actually benefit from less automated lexical access on some phonological processing tasks. Specifically, if sign forms are not rapidly de-activated due to less efficient access of lexical meaning, the phonological parameters of signs may be active in short term memory for a longer period of time promoting detection or analysis of these parameters. Further, the finding that handshape is processed differently by adolescent signers in many studies of phonological processing suggests that delayed exposure to language may impact the relative prominence of some phonological parameters over others. Despite multiple studies documenting an ability to detect and discriminate phonetic variation in signs, we know less about whether adolescent signers are sensitive to phonotactic constraints.

The only study to date to report findings related to sensitivity to sign phonotactics in native, childhood, and adolescent signers found only limited effects of age-of-acquisition. Orfanidou et al. (2009) presented participants with two sign sequences that consisted either of two nonsense signs ($n$ = 64) or a nonsense sign followed by a BSL sign ($n$ = 32). Participants, who were asked to identify any real signs in the stimuli, sometimes responded to a nonsense sign, misperceiving it as an actual BSL sign. These errors in perception have the potential to provide some clues to sensitivity to phonological parameters and sign phonotactics. However, native and early signers were not more likely than adolescent signers to correct phonotactically illegal vs. phonotactically legal signs. The only significant difference between the groups was the tendency for native and early signers to modify the movement of a nonsense sign in order to create an actual sign, while the adolescent signers were more likely to modify the handshape of the nonsense signs. Although these results reinforce the idea that later onset of language acquisition creates qualitative differences in the relative importance of different phonological parameters, we still have no evidence of differences in sensitivity to phonological well-formedness relative to age of acquisition.

Since this study concerns Polish Sign Language (*Polski Język Migowy*, PJM), its situation in Poland should be briefly presented from a historical perspective. In 2011, the Polish census put the number of PJM users at 983 (with the population of Poland being more than 38 million people)[1]. However, a more reliable number of PJM signers is fifty thousand as provided by the European Union of the Deaf (2022). The emergence of PJM is tied to the establishment of the Institute for the Deaf in Warsaw in 1817 by the efforts of Father Jakub Falkowski. In 1879, this first school for the deaf in Poland published one of the earliest sign language dictionaries in Europe (Hollak and Jagodziński, 1879) and it did not comply with the 1880 Milan Conference decision to ban sign language from deaf education (Trębicka-Postrzygacz, 2011). Despite all this, the use of PJM in deaf education did decline and it was not properly studied as a natural language (Tazbirówna, 1950 being a notable exception). Signing started to return to schools in the 1980s, but not in the form of a natural sign language, but rather signed Polish as the latter was, to no surprise, seen by the educational authorities as closer to Polish and as a sufficient compromise (Wojda, 2010;

[1]Later this year, it will be possible to compare this questionable number with the results of the 2021 census, during which a campaign was carried out to inform the Deaf about the possibility of choosing PJM as their home language.

Tomaszewski and Sak, 2014). The beginning of modern research on Polish Sign Language is attributed to a 1994 article, which was published in English by Michael Farris (Farris, 1994). In 2011, a law was passed recognizing PJM as a natural language of the Polish Deaf. Since 1994, interest in the scientific investigation of PJM has grown and new and innovative research is added every year. For example, even though PJM has been classified before as belonging to the German sign language family, it seems that it rather belongs to the French sign language family (Rutkowski and Sak, 2016).

The current study adds to the body of evidence about the CPL in two ways. First, this study investigates the effects of age of first language acquisition onset in PJM that has up until now received very little scientific investigation. The study builds on prior work by using a grammaticality judgment task, adapted for PJM. However, it is more comprehensive than prior studies by comparing sensitivity to phonological, morphological and syntactic structure within a single study. Specifically, the study asks participants who differ in their acquisition history to view a sequence of signs and signed sentences and judge their acceptability in PJM. By careful control of the phonological, morphological, and syntactic constraints that are manipulated during stimulus creation, the study is able to capture the breadth of age-of-acquisition effects in a single sample of participants.

Specifically, the study compared responses to utterances in PJM given by three groups:

(1) Native Signers – adult deaf signers with deaf parents, who learned PJM from birth;
(2) Childhood Signers – adult deaf signers with hearing parents, who learned PJM at the age of 4–8 years old, and
(3) Adolescent Signers – adult deaf signers with hearing parents, who learned PJM at the age of 9–13 years old.

The aim of the study was to evaluate differences or similarities between Native Signers, Childhood Signers, and Adolescent Signers in their sensitivity to phonological, morphological, and syntactic constraints in PJM utterances.

# MATERIALS AND METHODS

## Participants

Sixty-seven Deaf adults fluent in Polish Sign Language (PJM) were invited to participate in the study. Participants were recruited in cooperation with associations for the spread and development of deaf culture. On the basis of exclusion criteria, seven were removed from the analysis due to limited exposure to PJM in early life or because PJM was not their first language (two people learned from a deaf sibling using PJM; two people acquired PJM at the age of two; three people learned PJM as a second language after the age of 13). Of the remaining sixty participants, there were 33 women and 27 men. The mean age of participants was 33.4 (SD = 5.6). The youngest person was 24 years old and the oldest was 53 years old. The majority of participants were prelingually deaf (49 from birth; nine people lost their hearing before the age of one, and two people became deaf between the age of one and two). All of the participants had a profound hearing loss and attended preschools and schools for the deaf/hard-of-hearing (no participant attended mainstream preschool or school). All of the participants emphasized that PJM was their primary language (L1), used in their daily life and declared that their mastery of spoken and written Polish was weak or very weak. In order to find answers to the study questions, the participants were divided into three equal groups, according to the age of language acquisition groups described by Mayberry (1993).

### Native Polish Sign Language Signers

In the first group, all of the participants had deaf parents and acquired PJM from birth. This group included nine women and 11 men. All of the group members attended a preschool and school for the deaf.

### Childhood Polish Sign Language Signers

The second group consisted of 11 women and nine men. These participants acquired PJM as their first language at the age of four to eight when they started attending preschools and schools for the deaf where the majority of people used PJM. None of them learned spoken Polish before the age of four.

### Adolescent Polish Sign Language Signers

This group consisted of people who learned PJM as their first language at the age of nine to 13, and included 13 women and 7 men. Before their contact with PJM, late signers attended oral schools for the deaf/hard-of-hearing and had contact with Polish, but its progress proved to be impossible or delayed so much that they qualified for a school for the deaf, where the method of education of deaf students using sign language within the classroom was preferred.

**Table 1** provides a detailed summary of the sex, chronological age, age of acquisition, and the number of years of PJM use for each of the three participant groups.

## Materials

In order to measure participants' sensitivity to linguistic norms in PJM, the "Polish Sign Language Perception/Comprehension Test" (PJM-PCT) was used. The test is an exploratory tool developed by the first author (Tomaszewski, 2010, 2011, 2015; Tomaszewski and Farris, 2010) and in cooperation with native PJM signers who classified all stimuli according to their permissibility in PJM. And what is important: none of the native signers who were participants were involved in the development of the PJM-PCT.

The PJM-PCT measures sensitivity to three aspects of linguistic structure: phonological, morphological and syntactic. Part I of the test, consisting of 21 signs, served the purpose of assessing PJM sensitivity in terms of phonology. Part II of the test, consisting of 25 signs, was designed to assess sensitivity to morphology. Part III of the test, consisting of 12 signed sentences, verifies the level of familiarity with PJM syntax. In Parts I, II, and III, the task of the participant is to view a sign or sentence and choose one of two response options – *true*, if the sign or sentence would be used in PJM, or *false* if the sign or sentence would not be acceptable in PJM. Participants could view each

**TABLE 1** | Characteristics of the PJM participant groups.

| Group | *N* | Sex | | Chronological age | | Age of PJM acquisition | | Years of PJM use | |
|---|---|---|---|---|---|---|---|---|---|
| | | *F* | *M* | *M* (SD) | Range | *M* (SD) | Range | *M* (SD) | Range |
| Native signers | 20 | 9 | 11 | 32.8 (4.5) | 24–41 | – | 0 | 32.8 (4.5) | 24–41 |
| Childhood signers | 20 | 11 | 9 | 32.6 (7.1) | 25–53 | 5.2 (1.2) | 4–8 | 27.4 (7.1) | 19–48 |
| Adolescent signers | 20 | 13 | 7 | 34.9 (4.8) | 29–43 | 9.7 (1.2) | 9–13 | 25.2 (4.8) | 17–33 |

*F, female; M, male; M, mean; SD, standard deviation.*

stimulus two times prior to responding. There was no time limit for the response.

Strong internal reliability as measured with the Cronbach's alpha coefficient was found for the composite scores on the PJM-PCT ($\alpha = 0.91$). The reliability for the three sub-parts of the test was also good (Phonology: $\alpha = 0.80$; Morphology: $\alpha = 0.81$; Syntax: $\alpha = 0.72$). These values are satisfactory and highlight the good psychometric properties of the test.

## Phonology

In terms of phonology, the PJM-PCT presents participants with 21 stimuli: 11 target signs produced in citation form and 10 target signs with a change to one articulatory parameter. Following Brennan (1992), three sign types are distinguished: (1) manual signs, (2) non-manual signs, and (3) multi-channel signs. The first require only the use of the hands. According to Stokoe's (1978) model their internal structure includes three basic parameters: handshape, location and movement. A fourth parameter, observed by Battison (1978), is orientation. This parameter refers to the direction in which the palm is facing in relation to the signer. Although Sandler and Lillo-Martin (2006) argue that orientation is a constituent element of the handshape parameter, and is not a separate parameter, in creating the PJM-PCT, orientation was included in order to probe participants' sensitivity to a sign with the incorrect orientation. Nine trials on Part I of the test consisted of manual signs, among which four signs had an incorrect hand configuration, orientation or movement. For example, the sign MAMA "mother" is articulated incorrectly: instead of a hand configuration where the index and middle fingers are extended and the rest of the fingers are rolled into a fist, the hand configuration uses only one extended finger (see **Supplementary Video 1** for correct sign and **Supplementary Video 2** for incorrect form).

When formulating non-manual signs, other parts of the body are used instead of the hands, including facial expressions, body, head and eye movements, mouth gestures and even mouthings. Non-manual signs, which do not require the use of the hands, have been documented in PJM by Tomaszewski and Farris (2010). Non-manual signs function as lexemes and are not bound obligatorily with other morphemes. These non-manual signs are represented by the abbreviation NMS:___. PJM includes a non-manual sign NMS:ZGADZA-SIĘ, which is articulated by wrinkling the nose. It may be translated into English as "That's right." In signed conversations, this sign is used by the receiver of signed information to confirm or agree with the information being transmitted to them by the signer. The PJM-PCT does not include any trials with simple non-manual signs. In addition to simple non-manual signs, which include only one place of articulation, PJM also possesses complex non-manual signs, which have more than one location parameter. Articulating a given NMS can require the simultaneous use of different parts of the face. The PJM-PCT includes four trials with complex non-manual signs, out of which two are incorrect. The incorrect stimuli were created by replacing a facial parameter of an attested PJM sign with a parameter that is attested in PJM – but not in the specific configuration of the stimulus form. For example, one of them is NMS:UDAWAĆ "to pretend," which requires the simultaneous use of the tongue, lips, and one eye. With the lips somewhat open, the tongue pushes out the middle of the non-dominant cheek and quickly slides forward toward the lips; at the same time there is a slight squint of one eye. And the mistake is that the eye squint is replaced by nose wrinkling (see **Supplementary Video 3** for correct sign and **Supplementary Video 4** for incorrect form).

A third kind of sign are multi-channel signs: some signs consist of obligatory non-manual signals incorporated with a manual sign, as observed by Baker-Shenk (1983) for ASL. In PJM, there exist signs that require not only the correct use of the hands, but also of non-manual signals. For example, manual signs frequently are produced with obligatory mouth gestures (lip configuration), which are characteristic of sign languages and have nothing to do with oral articulation in a spoken language. From the perspective of linear phonology in PJM, lip configurations can be articulated in some multi-channel signs in either a simultaneous or a sequential way. A simultaneous use of lip configurations with multi-channel signs takes place when only one lip configuration is superposed over the entire structure of a signed word, which is articulated in a linear manner. The use of non-manual signals in other multi-channel signs has a sequential character and is dependent on the sequence of segments of initial and final location and movement of the hands. Temporal synchronization of specified non-manual components with these segments is subject to relevant phonological rules in the articulatory process of a given multi-channel sign in PJM (Tomaszewski and Farris, 2010). The PJM-PCT includes eight trials with multi-channel signs, on which four trials consist of the correct manual forms combined with incorrectly executed non-manual signals. As noted above, the incorrect non-manual signals are all attested in PJM, but not in the specific configurations presented in the incorrect stimuli. An example of this is the sign NA-WSZELKI-WYPADEK "just in case," which is typically accompanied by slightly pursed lips, similar to the articulation of/u/. The correct lip configuration is replaced by rounded lips that are not pursed, similar to the lip configuration when saying the sound/o/ (see **Supplementary Video 5** for correct sign and **Supplementary Video 6** for incorrect form). Another example is the sign NIEZARADNY, "shiftless," which includes the incorrect sequence of two lip configurations "fe" with the features [labiodental, $open_{tongue}$] instead of the correct combination "fu" with the features [labiodental, round] (see **Supplementary Video 7** for correct sign and **Supplementary Video 8** for incorrect form).

## Morphology

In order to assess sensitivity to PJM morphological features from the perspective of simultaneous and sequential morphology, 25 signs made up of two morphemes – lexical and bound – were used. Stimuli consisted of a main morpheme, which could stand alone, but in this task, it was presented with a bound morpheme that allows for the creation of a new, derived word. Twelve trials presented permissible multimorphemic signs, while 13 trials presented multimorphemic signs with infelicitous changes to the bound morpheme.

PJM allows for the modification of some signs by the use of non-manual components. Certain non-manual elements overlap simultaneously with manual lexical units giving them an added meaning. They can function as adjectival modifiers, which can be co-articulated with manual signs in nominal or adjectival roles (Tomaszewski and Farris, 2010). For example, PJM often employs the non-manual affix "af" meaning "something huge, large," which includes a sequence of two lip configuration features [open, labiodental]. This sequential structure of labial constituents makes up a bound morpheme, which adjectivally modifies the meaning of the sign, with which it is articulated simultaneously. PJM also possesses a group of non-manual morphemes with an adverbial meaning, which accompany some verbs and adjectives, referring qualitatively to internal properties of processes, features and states. One of these morphemes is a non-manual marker in the form of squinting of the eyes and wrinkling of the eyebrows functioning as an intensifier, which can be added optionally to signs with the function of a verb or an adjective. Part II of the PJM-PCT includes nine trials of multimorphemic signs with a simultaneous non-manual marker, called Simultaneous Signs, among which four are unacceptable signs, with the infelicity on the non-manual morpheme. For example, for the complex sign ROZWIJAĆ-SIĘ "develop," the correct articulation includes a combination of moving the right hand up, perpendicularly to the left hand and a reduplicated sequence of two lip configurations "papapa" with the features [bilabial, open] as a bound morpheme with the meaning of "gradually." It was performed incorrectly by changing the non-manual signal to the reduplicated sequence of two lip configurations "popopo" with the features [$bilabial_{forward}$, $open_{round}$] (see **Supplementary Video 9** for correct sign and **Supplementary Video 10** for incorrect form). Another example presents the signed utterance DOM MAŁY "small house": the second sign MAŁY "small" should be produced with the lip configuration with the features [bilabial] and [open]. In the actual stimulus, the sign was produced with the previously mentioned non-manual morpheme "af," which conflicts semantically with MAŁY.

Aside from the aforementioned simultaneous processes in PJM, there are also sequential processes. This phenomenon refers to affixes as bound morphemes which are linearly added to basic signs, from which complex morphemes with a new meaning are formed. One of them is the negative prefix $NEG_1$– , which comes from the sign of negation #NIE (Tomaszewski, 2015). The prefix $NEG_1$– is added to lexical morphemes in the roles of verbs and adjectives. This process is conditioned by morphophonological constraints, which determine to which basic words the morpheme $NEG_1$– can be added. Part II of the PJM-PCT includes eight trials of prefixed signs, among which four are incorrect. One example is the sign *$NEG_1$+OGLĄDAĆ "not watch," which contains the agrammatical sequence of movements (*convex arc + full circular), which breaks the morphophonological rule on movement as one of the basic parameters of a sign (see Tomaszewski, 2015). In order to correctly express the negation "not watch" in PJM, the sign OGLĄDAĆ "watch" is signed simultaneously with the negative non-manual element of head shaking.

Other sequential negative affixes that are included in the PJM-PCT test include two suffixes: –$NEG_4$ meaning lack of something's (not someone's) existence or presence and –$NEG_5$ that expresses great difficulty in doing something (Tomaszewski and Eźlakowski, 2021a)[2]. Even though these morphemes are unproductive suffixes belonging to PJM, in the framework of the PJM-PCT five suffixed signs were prepared, three of which are incorrect. For example, the utterance *MIGAĆ BIEGLE+$NEG_4$ "not sign fluently" is incorrect because the suffix –$NEG_4$ expresses non-existence and thus cannot be combined with the adverb BIEGLE "fluently." The sign #NIE would have to be used to express the construction "do not sign fluently." Another example is the incorrect utterance *PÓJŚĆ+$NEG_5$ "not go": the morpheme –$NEG_5$ does not semantically fit the lexeme PÓJŚĆ "to go," which instead is expressed by the sign NIE-MÓC "not be able/unable," which is a suppletive negative.

Another type of sequential morphology included in Part II of the PJM-PCT test were complex signs with a bound manual morpheme –CZYSTY with a metaphorical approximation of "clean," which takes on the meaning of "native/indigenous." This morpheme is a source of many signs with the same semantics (Tomaszewski and Piekot, 2015). For example, the utterance POLSKA+CZYSTY "Poland" and "clean" refers to a native Pole and AMERYKA+CZYSTY "America" and "clean" refers to a native American. And so three complex signs with the semantic suffix –CZYSTY, two of which are incorrect, are included in the PJM-PCT test. An example of these is the utterance *UCZCIWY+CZYSTY "honest" and "clean," where the sign UCZCIWY is suffixed incorrectly with the morpheme –CZYSTY, instead of which a different derivational morpheme –MOCNO with the meaning "strongly" should be added to this lexeme.

## Syntax

In order to verify sensitivity to syntactic rules, 12 signed sentences, six correct and six incorrect, were included as trials of Part III of the PJM-PCT. They are constructed correctly or incorrectly in terms of the function of the verb, sentence structure

[2]For clarity of this work we describe both –$NEG_4$ and –$NEG_5$ as suffixes. More precisely, however, we believe only the first one to be a suffix, while the second one we consider to be a postfix. For the explanation of the difference between the two, see the cited article.

and its construction. These sentences include classifier predicates (six examples), agreement verbs (four examples), and sentences with non-manual signals with scope over the entire sentence or a sentence constituent (two examples).

Classifier predicates combine a specific handshape referring to the shape or size of objects, or a semantic class (e.g., people, animals, or vehicles) with a movement referring to manner, path, and location. These constructions express an action by a person, animal, or a thing. Part III of the PJM-PCT includes, for example, the incorrect sentence:

(1) SAMOCHÓD *CL:1-podejść-do-mnie- *

car come to me

*"The car came (as a person) to me."

Where the movement executed from the side to the signing space in front is accompanied by the incorrect personal classifier (index finger extended upward, the rest of the fingers closed in a fist), referring to animate nouns, but limited to people. The sign SAMOCHÓD "car" should be accompanied by the classifier CL:B representing a vehicle (See **Supplementary Video 11** for correct sentence and **Supplementary Video 12** for incorrect form).

Another example of a syntactic violation in PJM involved sentences in which the endpoints of an agreement verb did not correspond to the locations of discourse participants:

(2) KOBIETA IX-y KSIĄŻKA *x-ODDAĆ-*mi* JUŻ

Woman this book give back-to me finish

*"This woman here (she over there) gave me back the book."

In example (2) the agreement verb -ODDAĆ- "give back" is articulated from an undefined location – not from where an anaphorical point referring to the woman had previously established the locus of the woman.

Non-manual signals (facial expressions) as an intonational form belonging to the prosodic system of sign language are employed in creating sentences of various kinds. The PJM-PCT includes, among others, an example of an incorrect sentence (3), in which a question is transformed into an infelicitous statement by removing an obligatory non-manual signal over the second half of the sentence.

______________________th

(3) MĘĘCZYZNA WĄSY IX-y, GŁUCHY *SŁYSZĄCY

man mustache this, deaf hearing

*"This man with a mustache is deaf hearing"

In (3) the initial signs MĘŻCZYZNA "man," wąsy "mustache," and pointing to the person are co-articulated with the correct non-manual signal (squinted eyes) for a topic marker (th), the sign GŁUCHY "deaf" lacks the accompaniment of the facial expression of lifted eyebrows and a slight tilt of the head forward, which would have signaled that this is a question. Without the non-manual signal, the second half of the sentence appears to be a statement, which is infelicitous given the semantics of the second phrase.

## Procedure

The study was conducted by a deaf person, fluent in PJM and in Polish. In the beginning, the study participants were asked to fill out a background questionnaire, after which they were instructed in Polish Sign Language on how to complete the tasks. Written instructions were also included on the test answer sheet.

In the first two parts of the experiment, a laptop and a projector were used to present the study participants with simple and compound signs in order from the list (Parts I and II of the test). The participants had to indicate on the answer sheet whether the presented signs were correct or not. The sheet contained numbers referring to the order of the test elements shown and letters P – true (pl. *prawda*) and F – false (pl. *fałsz*). The participants gave an answer after the presentation of each sign by encircling one of the letters. There was no time limit for giving the answer. The third part of the experiment was similar, with the exception that the presented material consisted of signed sentences (Part III of the test). Again, the objective for the participant was to indicate on the answer sheet whether each sentence is acceptable or not.

The data were analyzed with mixed effects logistic regression models fitted with the lme4 (version 1.1–28) and lmerTest (version 3.1–3) packages in R (R Development, Bates et al., 2015; R Core Team, 2022). All models included both fixed effects parameters and random intercepts for participants and items fit by maximum likelihood using Laplace Approximation. The linear predictors were related to the conditional mean of the response through the inverse link function defined in GLM. The dependent variable was accuracy. The significance level of statistical tests was set to $\alpha = 0.05$.

Seven models were fitted. The first model estimated the effect of language level (phonology, morphology, and syntax) and the effect of group (Native Signers, Childhood Signers, and Adolescent Signers) on PJM-PCT accuracy. The addition of *Age* and *Years of PJM use* factors did not show any significant influence on Accuracy ($p > 0.05$) and were not included in subsequent models. We then divided the data by language level and estimated the effects of language structure and group for each of the three parts of the PJM-PCT. Finally, we removed the Native Signers and refitted these three models to assess performance of the Adolescent Signers relative to the Childhood Signers. Tables of fixed and random effects for the last three models can be found at https://osf.io/pw2c9/.

# RESULTS

## Age of Polish Sign Language Acquisition: General Results and Components of Language

All models consistently demonstrated effects of age of acquisition of PJM on accuracy. **Table 2** presents the mean raw accuracy scores of each participant group on the phonological,

**TABLE 2 |** Mean accuracy (SD) for each group of participants on each subsection of the PJM-PCT.

| Components of language | Native signers ($n$ = 20) | Childhood signers ($n$ = 20) | Adolescent signers ($n$ = 20) |
|---|---|---|---|
| | ***M*** **(SD)** | ***M*** **(SD)** | ***M*** **(SD)** |
| Phonology (21 items) | 18.05 (2.46) | 15.1 (2.2) | 11.1 (3.13) |
| Morphology (25 items) | 22.5 (2.4) | 16.3 (2.25) | 13.95 (2.87) |
| Syntax (12 items) | 9.8 (1.79) | 6.75 (1.77) | 5.5 (1.57) |
| Total (58 items) | 50.35 (6.03) | 38.15 (3.94) | 30.55 (9.92) |

*M, mean; SD, standard deviation.*

morphological, and syntactic levels of the PJM-PCT as well as the total accuracy, and **Figure 1** presents the mean accuracy in percent correct for each participant group on each level. The results of the model estimating effects of language level (phonology, morphology, and syntax) and group (Native Signers, Childhood Signers, and Adolescent Signers) on PJM-PCT accuracy are reported in **Table 3** (Fixed Effects) and **Table 4** (Random Effects). For the Childhood Signers, the expected chance of accuracy for the full test (provided that the remaining explanatory coefficients of the model were kept constant – here and beyond) was 71% lower compared to the Native Signer group ($p < 0.001$). For the Adolescent Signers, the expected chance of accuracy for the full test was 91% lower compared to the Native Signer group ($p < 0.001$). The model also revealed interactions between language level and age of acquisition for the Native Signers and Childhood Signers. Specifically, there was a significantly greater likelihood of accuracy differences on the morphology ($p < 0.01$) and syntax ($p < 0.05$) sections of the test than on the phonology section relative to the Native Signers. Accuracy differences between the Native and Adolescent Signers, by contrast, were comparable for all three sections of the test (see **Table 2**).

## Effects of Age of Polish Sign Language Acquisition on Phonology, Morphology, and Syntax

Accuracy on each level of the PJM-PCT was modeled separately in order to compare performance on the specific structures included in each part. Accuracy was modeled with and without Native Signers, with Native Signers as the baseline when all three groups were included and Childhood Signers as the baseline for Childhood vs. Adolescent models.

### Phonology

Accuracy on the phonology portion of the test was modeled with fixed effects of Group and Structure, including: Manual Signs, Non-manual Signs, and Multi-Channel Signs. Multi-Channel Signs were set as the baseline. All participant groups made more errors on the Non-manual Signs ($p < 0.01$). The expected chance of accuracy on all of the phonology items for the Childhood Signers was 85% lower compared to the Native Signers ($p < 0.001$). For the Adolescent Signers, the expected chance of accuracy was 97% lower compared to the Native Signers ($p < 0.001$), and 82% lower compared to the Childhood Signers ($p < 0.001$). There was a significantly greater likelihood of a difference in accuracy between Native and Adolescent Signers on the Multi-Channel Signs relative to the Manual Signs ($p < 0.05$). Likewise, the likelihood of a significant accuracy difference for Multi-Channel Signs relative to the Non-manual Signs was greater for Adolescent signers relative to both Native ($p < 0.001$) and Childhood ($p < 0.01$) signers. See **Figure 2** and **Table 5** (Fixed Effects) and **Table 6** (Random Effects).

### Morphology

Accuracy on the morphology portion of the test was modeled with fixed effects of Group and Structure, including: Simultaneous Signs, Negative Prefixes, Negative Suffixes, and Semantic Suffixes. Simultaneous Signs were set as the baseline. All participant groups made more errors on Semantic Suffixes ($p < 0.05$) than Simultaneous Signs. The expected chance of accuracy on all morphology items for the Childhood Signers was 85% lower compared to the Native Signer group ($p < 0.001$). For the Adolescent Signers, the expected chance of accuracy was 93% lower compared to the Native Signer group ($p < 0.001$), and 51% lower compared to the Childhood Signer group ($p < 0.05$). Relative to the Simultaneous Signs, the likelihood of accuracy differences between the Adolescent and Native signers was significantly greater for Negative Suffixes ($p < 0.05$) and significantly smaller for Semantic Suffixes ($p < 0.05$). See **Figure 3** and **Table 7** (Fixed Effects) and **Table 6** (Random Effects).

### Syntax

Accuracy on the syntax portion of the test was modeled with fixed effects of Group and Structure, including: Sentences with Classifier Predicates, Sentences with Agreement Verbs, and Sentences with Non-manual Signals. Sentences with Classifier Predicates were set as the baseline. The expected chance of accuracy on all syntax items for the Childhood Signers was 72% lower compared to the Native Signers ($p < 0.01$). For the Adolescent Signers, the expected chance of accuracy was 91% lower compared to the Native Signers ($p < 0.001$), and 62% lower compared to Childhood Signers ($p < 0.01$). The likelihood of accuracy differences between the Childhood and Native Signers was significantly greater for Sentences with Agreement Verbs than Sentences with Classifier Predicates ($p < 0.05$). No differences in the relative likelihood of accuracy differences for specific syntactic structures were found for the Adolescent Signers and either the Native or Childhood Signers. See **Figure 4** and **Table 8** (Fixed Effects) and **Table 6** (Random Effects).

## DISCUSSION

The study described in this work was designed to gather evidence relevant to the critical period hypothesis for language from first language learners. Moreover, the study provides data from a less-commonly studied signed language, PJM, and from multiple levels of language structure – phonology, morphology and syntax. The results display a consistent pattern across all analyses:

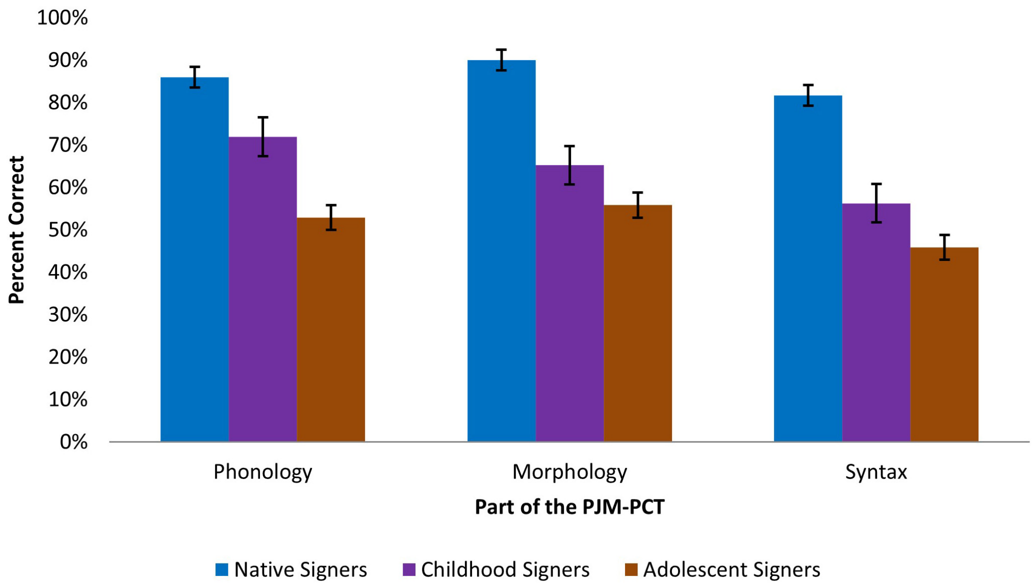


**FIGURE 1 |** Percent accuracy on the three sections of the PJM-PCT by age of PJM acquisition.

**TABLE 3 |** The coefficients of a generalized linear mixed-effects two-factor model with fixed effects of language level (phonology, morphology, and syntax) and group (native signers, childhood signers, and adolescent signers) and accuracy as the dependent variable.

| ***Predictors*** | **Accuracy** | | |
|---|---|---|---|
| | ***Odds ratios*** | ***95% CI*** | ***p*** |
| (Intercept) | 17.38 | 7.14–42.28 | **<0.001** |
| Morphology | 1.30 | 0.42–4.04 | 0.652 |
| Syntax | 0.63 | 0.16–2.48 | 0.511 |
| Childhood signers | 0.29 | 0.16–0.51 | **<0.001** |
| Adolescent signers | 0.09 | 0.05–0.16 | **<0.001** |
| Morphology × Childhood signers | 0.43 | 0.25–0.75 | **0.003** |
| Syntax × Childhood signers | 0.51 | 0.27–0.99 | **0.045** |
| Morphology × Adolescent signers | 0.82 | 0.47–1.44 | 0.490 |
| Syntax × Adolescent signers | 0.88 | 0.45–1.71 | 0.697 |

*CI, confidence interval.*
*Statistically significant p-values are in bold.*

**TABLE 4 |** The random effects of a generalized linear mixed-effects two-factor model for all language levels and all groups.

| **Random effects** | |
|---|---|
| $\sigma^2$ | 3.29 |
| $\tau_{00\,Participant}$ | 0.43 |
| $\tau_{00\,Item}$ | 3.09 |
| ICC | 0.52 |
| $N_{Item}$ | 58 |
| $N_{Participant}$ | 60 |
| $N_{Observations}$ | 3480 |
| Marginal $R^2$/Conditional $R^2$ | 0.154/0.591 |

*$\sigma^2$, the variability across individuals; $\tau_{00}$, the random intercept variance; ICC, intraclass correlation coefficient; N, number; $R^2$, the coefficient of determination.*

Native Signers produced significantly different responses than Childhood and Adolescent Signers when asked what signs and signed sentences are acceptable in PJM. This finding applies to the entire test, and to each linguistic level of the test (phonology, morphology, and syntax). The results demonstrate that the age of acquisition of PJM substantially influences sensitivity to grammatical constraints in highly experienced adult signers, consistent with Lenneberg's (1967) theoretical predictions, and with pioneering research on ASL (Mayberry and Fischer, 1989; Newport, 1990; Mayberry and Eichen, 1991; Mayberry, 1993; Boudreault and Mayberry, 2006).

No prior studies using grammaticality judgment to explore age of acquisition effects have included signs that do not conform to phonological constraints. The current study revealed substantial differences in sensitivity to PJM phonological constraints between all the groups. Similar to the general results, Native Signers were the most sensitive to PJM phonological constraints; Childhood Signers were significantly less sensitive than Native Signers but significantly more sensitive than Adolescent Signers; the least sensitivity to phonological constraints was exhibited by Adolescent Signers. These results might seem inconsistent with prior studies showing preserved phonological processing skills in signers who acquired ASL in adolescence. Note, however, that all studies that report comparable or better performance of late signers relative to native signers used tasks that did not entail semantic processing of the stimuli, such as handshape discrimination and monitoring tasks (Morford et al., 2008; Best et al., 2010; Morford and Carlson, 2011). In the current study, participants were not asked specifically to attend to the meaning of the signs, but in order to decide whether or not the signed stimuli were acceptable in PJM or not, participants most likely considered not only form, but also meaning.

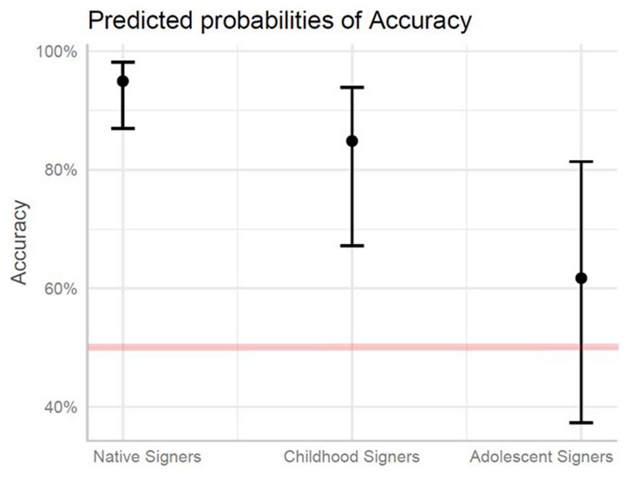


**FIGURE 2 |** Predicted probabilities of accuracy for native signers, childhood signers, and adolescent signers for phonology. The red line denotes chance responding (50%).

**TABLE 5 |** The coefficients of a generalized linear mixed-effects two-factor model with fixed effects of phonological structure (manual signs, non-manual signs, and multi-channel signs) and group (native signers, childhood signers, and adolescent signers) and accuracy as the dependent variable.

| | Accuracy | | |
|---|---|---|---|
| ***Predictors*** | ***Odds ratios*** | ***CI*** | ***p*** |
| (Intercept) | 86.60 | 17.04–440.12 | **<0.001** |
| Manual signs | 0.22 | 0.03–1.75 | 0.152 |
| Non-manual signs | 0.03 | 0.00–0.34 | **0.005** |
| Age of PJM acquisition [Childhood signers] | 0.15 | 0.06–0.41 | **<0.001** |
| Age of PJM acquisition [Adolescent signers] | 0.03 | 0.01–0.07 | **<0.001** |
| Manual signs × Childhood signers | 2.87 | 0.99–8.35 | 0.053 |
| Non-manual signs × Childhood signers | 1.70 | 0.55–5.30 | 0.358 |
| Manual signs × Adolescent signers | 3.67 | 1.25–10.76 | **0.018** |
| Non-manual signs × Adolescent signers | 7.83 | 2.46–24.90 | **<0.001** |

*Statistically significant p-values are in bold.*

**TABLE 6 |** The random effects of generalized linear mixed-effects two-factor models for each language level and all groups.

| | Random effects | | |
|---|---|---|---|
| | ***Phonology*** | ***Morphology*** | ***Syntax*** |
| $\sigma^2$ | 3.29 | 3.29 | 3.29 |
| $\tau_{00\,Participant}$ | 0.53 | 0.25 | 0.43 |
| $\tau_{00\,Item}$ | 3.63 | 2.16 | 2.06 |
| ICC | 0.56 | 0.42 | 0.43 |
| $N_{Item}$ | 21 | 25 | 12 |
| $N_{Participant}$ | 60 | 60 | 60 |
| $N_{Observations}$ | 1260 | 1500 | 720 |
| Marginal $R^2$/Conditional $R^2$ | 0.234/0.662 | 0.229/0.555 | 0.288/0.595 |

*$\sigma^2$, the variability across individuals; $\tau_{00}$, the random intercept variance; ICC, intraclass correlation coefficient; $R^2$, the coefficient of determination.*

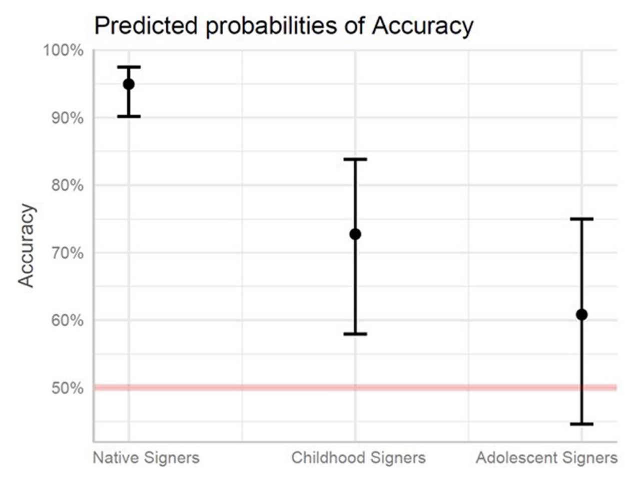


**FIGURE 3 |** Predicted probabilities of accuracy for native signers, childhood signers, and adolescent signers for morphology. The red line denotes chance responding (50%).

The results of this study complement the findings of Lieberman et al. (2015), who gathered eye-tracking data while signers watched a sign and then selected a matching photograph from four options. When phonological distractors were included among the response options, native signers were slower to select the target picture, and fixated distractor pictures more often than in the control condition. Signers who were first exposed to ASL between the ages of 5 and 14 years of age were slightly slower than the native signers to shift their attention from the signed stimulus to the response photographs across all conditions. But the more striking result was that their looking behavior was not influenced by the presence of phonological distractors. Lieberman et al. argue that non-native signers do not activate sub-lexical features of signs in real time. If this was the case in the current study, Adolescent Signers may have been more likely to accept a sign violating phonological constraints due to a high degree of overall similarity to a known sign than to reject it due to a change detected in the sub-lexical structure.

Note that Lieberman et al. (2015) included targets and distractors that varied along the three basic parameters of hand configuration, location and movement. In this study, participants had to make judgments of stimuli consisting solely of non-manual signals (both conforming to and violating phonological constraints) as well as multi-channel signs in which the non-manual component rather than the manual parameters had been manipulated. All participants found it particularly difficult to detect violations in stimuli consisting solely of non-manual signals. Age of acquisition effects were particularly pronounced for multi-channel signs that required signers to split their attention between manual and non-manual features of the stimuli. Indeed, our results are the first to demonstrate that the earlier one is exposed to non-manual elements, the more sensitive one becomes to the occurrence of these components both at the sublexical and lexical levels. Acquisition of the manual phonological parameters was more robust in the face of delayed

**TABLE 7 |** The coefficients of a generalized linear mixed-effects two-factor model with fixed effects of morphological structure (simultaneous signs, negative prefixes, negative suffixes, and semantic suffixes) and group (native signers, childhood signers, and adolescent signers) and accuracy as the dependent variable.

| | Accuracy | | |
|---|---|---|---|
| ***Predictors*** | ***Odds ratios*** | ***CI*** | ***p*** |
| (Intercept) | 36.47 | 10.93–121.67 | **<0.001** |
| Negative prefix | 0.35 | 0.07–1.81 | 0.211 |
| Negative suffix | 1.52 | 0.21–11.18 | 0.680 |
| Semantic suffix | 0.11 | 0.01–0.92 | **0.041** |
| Age of PJM acquisition [Childhood signers] | 0.15 | 0.07–0.33 | **<0.001** |
| Age of PJM acquisition [Adolescent signers] | 0.07 | 0.03–0.16 | **<0.001** |
| Negative prefix × Childhood signers | 0.97 | 0.37–2.51 | 0.948 |
| Negative suffix × Childhood signers | 0.29 | 0.08–1.03 | 0.055 |
| Semantic suffix × Childhood signers | 2.41 | 0.79–7.34 | 0.121 |
| Negative prefix × Adolescent signers | 1.62 | 0.62–4.20 | 0.323 |
| Negative suffix × Adolescent signers | 0.19 | 0.05–0.73 | **0.015** |
| Semantic Suffix × Adolescent Signers | 3.60 | 1.18–10.99 | **0.025** |

*Statistically significant p-values are in bold.*

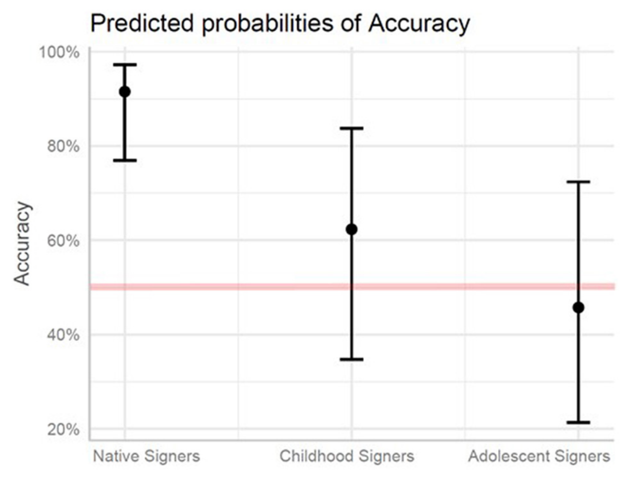


**FIGURE 4 |** Predicted probabilities of accuracy for native signers, childhood signers, and adolescent signers for syntax. The red line denotes chance responding (50%).

acquisition. A tentative hypothesis based on these results is that within phonological features, sensitivity to non-manual signals is more dependent on early exposure than sensitivity to the three manual parameters. However, additional research in this direction is needed to investigate thoroughly the dependencies between sublexical parameters from the perspective of their relationship to CPL. Further, studies of the processing of manual and non-manual phonological parameters by deaf and hearing L2 learners may help to elucidate these dependencies.

Turning to the morphological level, the results again demonstrated greater sensitivity to grammatical constraints by Native Signers as compared to Childhood Signers and Adolescent Signers, for both simultaneous and sequential bound morphemes. Prior research on ASL has shown effects of age of acquisition on the production and comprehension of simultaneous multimorphemic verb constructions (Newport, 1990), but this is the first study to specifically test sensitivity to sequential morphology as well. The results indicate that signers first exposed to a signed language in adolescence have particular difficulty with negative suffixes. This could be an indication that detecting grammatical patterns that are distributed across multiple signed syllables is particularly challenging. It is worth mentioning that during the current experiment, it was observed that Native Signers paraphrased some sign expressions while preparing to respond. Their paraphrases, particularly for prefixed signs, demonstrated their awareness of morphophonological constraints. In order to paraphrase these signs and determine whether they were correct or not, they had to use linguistic knowledge about internal morphology.

**TABLE 8 |** The coefficients of a generalized linear mixed-effects two-factor model with fixed effects of syntactic structure (classifier predicates, verb agreement, and non-manual signals) and group (native signers, childhood signers, and adolescent signers) and accuracy as the dependent variable.

| | Accuracy | | |
|---|---|---|---|
| ***Predictors*** | ***Odds ratios*** | ***CI*** | ***p*** |
| (Intercept) | 17.33 | 4.36–68.85 | **<0.001** |
| Sentences with agreement verbs | 0.18 | 0.02–1.34 | 0.093 |
| Sentences with non-manual signals | 0.84 | 0.06–11.69 | 0.899 |
| Age of PJM acquisition [Childhood signers] | 0.28 | 0.11–0.67 | **0.004** |
| Age of PJM acquisition [Adolescent signers] | 0.09 | 0.04–0.23 | **<0.001** |
| Sentences with agreement Verbs × Childhood signers | 0.31 | 0.10–0.94 | **0.039** |
| Sentences with non-manual signals × Childhood signers | 0.63 | 0.14–2.83 | 0.542 |
| Sentences with agreement verbs × Adolescent signers | 0.52 | 0.16–1.68 | 0.279 |
| Sentences with Non-manual signals × Adolescent signers | 1.83 | 0.40–8.29 | 0.432 |

*Statistically significant p-values are in bold.*

At the level of syntax, Native Signers showed greater sensitivity to classifier predicates, verb agreement constructions and non-manual signals marking syntactic roles than Childhood Signers or Adolescent Signers. Childhood signers were more likely to overlook violations in verb agreement constructions than classifier predicates. These results are consistent with and build on the research results of Newport (1990), who found that late first-language signers were much less consistent in their comprehension and production of classifier predicates and verb agreement than native signers. Likewise, Emmorey et al. (1995a) found that verb agreement errors disrupted Native Signers during a sign monitoring task, whereas Adolescent Signers didn't demonstrate a disruption of performance due to the errors. However, in contrast to the current findings, Emmorey et al.'s participants were able to detect verb agreement errors in a grammaticality judgment task. Despite minor inconsistencies across these three studies, the fact that Childhood and Adolescent Signers do not always detect grammatical anomalies, particularly when the stimuli are novel or the task requires an immediate response, is a strong indicator that a delay in the onset of acquisition impacts the stability and predictability of linguistic knowledge. Berk (2004), who studied the acquisition of ASL verb agreement longitudinally in two deaf children who were first exposed to ASL at the age of 6, found that errors of omission and commission were more common in her participants than in children with comparable years of exposure to ASL, but who had started acquiring ASL from birth. She argued that the patterns found among adult signers have their roots in the earliest phases of acquisition.

An ongoing debate in the CPL literature concerns the age after which full mastery of language is no longer possible. Hartshorne et al. (2018; cf. Chen and Hartshorne, 2021) used a massive dataset from second language learners of English to argue that there is a discontinuity in the ability to learn syntax for individuals who were not exposed to their second language until age 17.4 or later (but see Slik et al., 2021). Consistent with Mayberry and Kluender's (2018) argument, our study results show that effects of delayed exposure to language occur much earlier than 17 years when considering a first language. The Adolescent Signer group, that differed significantly from the native signers on all measures, were exposed to PJM between the ages of 9 and 13 and had used PJM for an average of 25 years. The Childhood Signer group, who were exposed to PJM between the ages of 4 and 8, and had used PJM for an average of 27 years, also showed significant differences from the native signers on the test as a whole, and on all three levels of the test, suggesting that for a first language, exposure to accessible input cannot be delayed beyond 4 years without consequences for acquisition. The fact that neither age nor years of PJM experience improved the models is further confirmation of our conclusion that the current results reflect the impact of age of first language acquisition effects and not language experience more generally.

Although the current results are entirely behavioral, evidence from neuroimaging studies supports these conclusions. In a brain imaging study conducted by Mayberry et al. (2011), they found decreasing levels of activation in left hemisphere anterior areas during a grammaticality judgment task, and increasing levels of activation in left hemisphere posterior areas as age of acquisition increased. Similar results were found when participants were asked to distinguish between one- and two-handed signs. In a subsequent study, Cheng et al. (2019) used fractional anisotropy to estimate the white matter density of four neural pathways associated with language processing. They found no differences in white matter density between 12 deaf and 12 hearing ASL signers even though ASL was a first language for the deaf participants and a second language for the hearing participants. Both groups exhibited greater left hemisphere than right hemisphere white matter density in the left dorsal arcuate fasciculus pathway. By contrast, three deaf individuals who learned ASL at the age of 13 or later exhibited significantly less white matter density of the left dorsal arcuate fasciculus pathway than the two control groups. Further, the late learners did not show the same left hemisphere lateralization pattern. They had similar degrees of white matter density in the left and right hemispheres. These neurodevelopmental results expand on Penfield and Roberts (1959) hypothesis related to increased difficulties in learning a language with age, because of the change in neural connections in the brain. As Mayberry and Kluender (2018, p. 900) argue, the unique neural systems underlying language processing are the outcome of "temporally synchronized" brain maturation and language development. This position is elaborated by Reh et al. (2020) who describe how plasticity in brain development must be investigated across multiple timescales to provide a satisfactory account of the mechanisms underlying the development of complex cognitive functions such as language. Language is dependent upon the coordination of brain systems each with unique periods of maximum plasticity. Effects of deprivation could potentially change cellular function, leading to excitatory-inhibitory imbalance, the regulation of gene expression relative to environmental input, as well as the developmental trajectory of physiological systems across the lifespan.

From a usage-based perspective on language development, we would argue that the differences in performance of the three groups in the current study reflect optimization of different amounts and distributions of input combined with different timing of input over early development. The Childhood and Adolescent Signer groups were not idle prior to their exposure to PJM but instead were adapting to a communicative environment that was sparsely populated with structured communication events. Prior to exposure to PJM, participants from these groups were generating structured communication in the form of homesigns. Even if these systems did not provide a basis for acquiring PJM comparable to the early linguistic experience of those who acquire PJM as a second language, these homesign systems were likely important for development (Morford and Hänel-Faulhaber, 2011). Despite poor language learning conditions, childhood and adolescent signers develop homesign systems containing many, but not all, of the properties of natural language (Goldin-Meadow, 2003). Moreover, the research of Tomaszewski (2003) shows that deaf preschoolers in oral education contexts and without access to PJM at home develop innovative gesture systems at school over a 2-year period, which he calls *preschoolsign*. In the peer context of a school setting, but without PJM input – the homesign of one child served as a linguistic model for another homesigner, and the children adopted but also adapted features of each other's systems. Hence the preschoolsign system – originated and developed by preschoolers – is a phenomenon that allows us to observe and describe, as defined by Morford and Kegl (2000), gestural precursors to linguistic constructs. In Tomaszewski's research the preschoolsign system is characterized by displacement and arbitrariness: preschoolsigners can talk about things removed in time and space from their personal experience; preschoolsigners also generate signs that do not necessarily resemble their referents. Moreover, these signs consist of smaller parts that can be recombined to produce new signs with different meanings (cf. Goldin-Meadow et al., 1995). It was also observed that preschoolsigners display an ability to mentally represent non-linguistic reality by expressing predicate argument structures in the form of signs that fulfill various thematic roles. And besides, their utterances included negation, with the gestures being the lexical means of expressing propositional functions. These symbolic gestural constructs reflect the deaf preschoolers' general cognitive development. More importantly, new linguistic elements emerge in the preschoolsign system, ones which are not found in the earlier homesign systems and which appear to require gestural communication in contact among preschoolsigners. As Kegl (2018) notes, *contact gesturing*, with its many characteristics not encountered in isolated gesturing, feeds language creation.

## LIMITATIONS AND FUTURE DIRECTIONS

Despite our efforts at all stages of implementation, the conducted research exhibits some limitations, which need to be taken into account when interpreting the above results and planning future studies based on these results. The first limitation is the exploratory character of the PJM-PCT test – thus, an update of the PJM-PCT test content is necessary. Even though this tool was reliable and the values for the individual linguistic aspects showed good psychometric characteristics, it would be advisable to widen the PJM-PCT to include a larger number of trials at each level. For example, on the phonology sub-test, one improvement would be to include simple non-manual signs, which are currently missing from the PJM-PCT, since all participants exhibited difficulty with the complex non-manual signs. On the morphology sub-test, more stimuli with the semantic suffix –CZYSTY are needed, as mentioned before. It would also be beneficial to supplement this sub-test with temporal suffixes described by Tomaszewski and Eźlakowski (2021b) since there are some constraints on the use of these morphemes when used with numeral incorporation. Similarly in the area of syntax it would be beneficial to add more trials to improve the power of analyses of the individual structures included on this sub-test. Moreover, it would be good to prepare other kinds of sentences, such as those included by Boudreault and Mayberry (2006): simple and negated sentences. These authors compiled ungrammatical sentences that were created by moving a constituent to an incorrect position in the sentence, which was not included in the PJM-PCT. The current agrammatical items on the syntax sub-test were created by replacing the correct predicate with signs that were incompatible with the sentence context (incorrect classifier handshape for the preceding noun; incorrect loci of agreement verbs relative to the spatial locus of referents in the sentence). It is worth noting that independent manipulation of morphology and syntax is challenging in PJM since morphemes often have sentence-level functions. For example, in classifier predicates correct handshape refers to some formal or semantic properties of a referent but also encodes a grammatical role within the classifier construction. Likewise, the movement of agreement verbs indexes syntactic constituents, while the handshape can indicate semantic properties of an instrument or direct object. Hence, it would be useful to create sentence stimuli to assess word order in PJM – in order to better distinguish the effects of age of acquisition on morphology and syntax.

Another limitation of this research was the narrow scope of variables included in the background questionnaire, which should be expanded so that we can collect specific information about the frequency and intensity of contact with sign language by the participants and people from their close surroundings (e.g., family members, teachers, tutors) and the educational environment (whether the participants, as students, spent most of the time at a boarding school or at home; whether the participants interacted with deaf peers who were native signers even though they attended an oral school, etc.). This kind of information is necessary for the subtle differentiation of language learning histories and to characterize early communication systems such as homesign, which, according to Koulidobrova and Pichler (2021), should be considered the "initial systems" used by participants, and included in the consideration of language learning outcomes. Another limitation in the study was the fact that we relied on participants' self-assessment that their Polish language knowledge was weak or very weak rather than using a direct assessment. In future research, we plan to test the knowledge of Polish – at least when it comes to reading skills – to provide a more complete picture of the linguistic experiences of the respondents.

Finally, it is important to acknowledge that some findings may not generalize beyond the context of signed languages since there are no comparable studies of childhood or adolescent learners of spoken languages with which to compare these results. Thus, effects of age of acquisition may intersect with modality-specific constraints, such as the degree to which facial expression must conform to phonological constraints. Despite the above-mentioned limitations, this study enriches our understanding of the critical period for language with data from a language learning context that is not widely available for study.

## CONCLUSION

The implication of our findings, as well as previous studies showing that there is a negative correlation between age of sign language acquisition and sensitivity to grammatical constraints, is that the *environment* of individuals at risk of language deprivation must be changed to ensure unfettered access to language. Insufficient exposure to language in early development has irreversible effects. This pattern is identified by some researchers as evidence for a neurodevelopmental disorder rooted in preventable socially conditioned child-rearing behaviors and societal medical and early childhood education policies. *Language Deprivation Syndrome* (LDS) is defined as a consequence of chronic lack of full access to a natural language during the critical period for language (CPL) (Hall et al., 2017b, 2019; Gulati, 2018). In the past, language deprivation among deaf children was related in part to the late identification of deafness, but given improvements in hearing detection, it is important to acknowledge that currently "the delay in language input is due to a medical model of deafness that prioritizes *hope* for the eventual acquisition of spoken language over the immediate need for exposure to *accessible* language" (Hecht, 2020; p. 1320). As Mayberry (2010) emphasizes, despite awareness of the importance of the age of exposure to language for language acquisition outcomes, insufficient actions have been taken to ensure that all deaf children are exposed to accessible language from an early age. Educational programs directed at deaf late-signer children – also in Polish circumstances – should be developed based on conclusions from normative PJM research and using tools for the evaluation of linguistic competence in PJM (Tomaszewski, 2010, 2011, 2015; Rutkowski et al., 2015, 2017; Wiśniewska-Jankowska, 2016; Kotowicz et al., 2021).

Language deprivation not only affects language development. It can also lead to related effects in cognitive function, which are based on the mastery of the first language (see Hall et al., 2017a). Further, LDS impacts mental health outcomes of deaf individuals. Kushalnagar et al. (2020) provide evidence that Adverse Childhood Communication Experiences (ACCE) such as poor child-caregiver communication and less inclusion of children in household communication are associated with higher rates of medical complications including diabetes, hypertension, heart and lung disease, and depression. Likewise, Wilkinson and Morford (2020) argue that bilingualism can act as a protective measure against health risks in the deaf population and should be incorporated as a standard of care for culturally and linguistically appropriate services to deaf people. In sum, the effects of language deprivation in early childhood reach far beyond linguistic outcomes. Increased social awareness in regards to all aspects of this problem are needed to stimulate changes that will address the environmental barriers to early linguistic development for all deaf children.

## DATA AVAILABILITY STATEMENT

Source data and R code associated with this article can be found at: Tomaszewski et al. (2022).

## ETHICS STATEMENT

Ethical approval was granted by the Ethics Committee of the Faculty of Psychology, University of Warsaw, prior to recruiting participants. The participants provided their written informed consent to participate in this study. Informed consent was obtained from the individuals for the publication of identifiable videos in the supplementary materials for this article.

## AUTHOR CONTRIBUTIONS

PT: conceptualization, methodology, data collection, analysis, writing – original draft preparation, and funding. PK: methodology, data collection, analysis, writing, and literature review. JM: literature review and editing. WE: editing and translation. All authors contributed to the article and approved the submitted version.

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## SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2022.896339/full#supplementary-material

**Supplementary Video 1 |** Correct sign MAMA "mother."

**Supplementary Video 2 |** Incorrect form of sign MAMA "mother."

**Supplementary Video 3 |** Correct sign UDAWAC "to pretend."

**Supplementary Video 4 |** Incorrect form of sign UDAWAC "to pretend."

**Supplementary Video 5 |** Correct sign NA-WSZELKI-WYPADEK "just in case."

**Supplementary Video 6 |** Incorrect form of sign NA-WSZELKI-WYPADEK "just in case."

**Supplementary Video 7 |** Correct sign NIEZARADNY "shiftless."

**Supplementary Video 8 |** Incorrect form of sign NIEZARADNY "shiftless."

**Supplementary Video 9 |** Correct sign ROZWIJAC-SIE "develop gradually."

**Supplementary Video 10 |** Incorrect form of sign ROZWIJAC-SIE "develop gradually."

**Supplementary Video 11 |** Correct PJM sentence.

**Supplementary Video 12 |** Incorrect form of PJM sentence.

## REFERENCES

Baker-Shenk, C. (1983). *A Micro-analysis of the Nonmanual Components of Questions in American Sign Language.* Ph.D. dissertation. Berkeley, CA: University of California.

Bates, D., Machler, M., Bolker, B., and Walker, S. (2015). Fitting linear mixed-effects models using lme4. *J. Stat. Softw.* 67, 1–48. doi: 10.18637/jss.v067.i01

Battison, R. (1978). *Lexical Borrowing in American Sign Language.* Silver Spring: Linstok Press.

Bellugi, U., Klima, E. S., and Siple, P. (1975). Remembering in signs. *Cognition* 3, 93–125. doi: 10.1016/0010-0277(74)90015-8

Berk, S. (2004). "Acquisition of verb agreement when first-language exposure is delayed," in *Proceedings of the 28th Annual Boston University Conference on Language Development*, 1, eds A. Brugos, L. Micciulla, and C. E. Smith (Somerville, MA: Cascadilla Press), 62–73.

Best, C. T., Mathur, G., Miranda, K. A., and Lillo-Martin, D. (2010). Effects of sign language experience on categorical perception of dynamic ASL pseudosigns. *Atten. Percept. Psychophys.* 72, 747–762. doi: 10.3758/APP.72.3.747

Boudreault, P., and Mayberry, R. I. (2006). Grammatical processing in american sign language: age of first-language acquisition effects in relation to syntactic structure. *Lang. Cogn. Process.* 21, 608–635. doi: 10.1080/01690960500139363

Brennan, M. (1992). "The visual world of BSL: an introduction," in *The Dictionary of British Sign Language/English*, ed. D. Brien (London: Faber & Faber), 1–134. doi: 10.1215/9780822395546-001

Chen, T., and Hartshorne, J. K. (2021). More evidence from over 1.1 million subjects that the critical period for syntax closes in late adolescence. *Cognition* 214:104706. doi: 10.1016/j.cognition.2021.104706

Cheng, Q., Roth, A., Halgren, E., and Mayberry, R. I. (2019). Effects of early language deprivation on brain connectivity: language pathways in deaf native and late first-language learners of American Sign Language. *Front. Hum. Neurosci.* 13:320. doi: 10.3389/fnhum.2019.00320

R Core Team (2022). *R: A language and environment for statistical computing.* Vienna: R Foundation for Statistical Computing.

Cormier, K., Schembri, A., Vinson, D., and Orfanidou, E. (2012). First language acquisition differs from second language acquisition in prelingually deaf signers: Evidence from sensitivity to grammaticality judgement in British Sign Language. *Cognition* 124, 50–65. doi: 10.1016/j.cognition.2012.04.003

Emmorey, K., Bellugi, U., Friederici, A., and Horn, P. (1995a). Effects of age of acquisition on grammatical sensitivity: evidence from on-line and off-line tasks. *Appl. Psycholinguist.* 16, 1–23. doi: 10.1017/S0142716400006391

Emmorey, K., Corina, D., and Bellugi, U. (1995b). "Differential processing of topographic and referential functions of space," in *Language, Gesture, and Space*, eds K. Emmorey and J. S. Reilly (Hillsdalle, NJ: Lawrence Erlbaum Associates), 43–62.

European Union of the Deaf (2022). *Poland*. Available online at: https://www.eud.eu/member-countries/poland/ (Accessed: April 1, 2022)

Farris, M. (1994). Sign language research and polish sign language. *Ling. Posnan.* 36, 13–36.

Goldin-Meadow, S. (2003). *The Resilience of Language: What Gesture Creation in Deaf Children Can Tell Us About How All Children Learn Language*. New York, NY: Psychology Press.

Goldin-Meadow, S., Mylander, C., and Butcher, C. (1995). The resilience of combinatorial structure at the word level: morphology in self-styled gesture systems. *Cognition* 56, 195–262. doi: 10.1016/0010-0277(95)00662-i

Gulati, S. (2018). "Language deprivation syndrome," in *Language Deprivation and Deaf Mental Health*, eds N. S. Glickman and W. Hall (New York, NY: Routledge), 24–53. doi: 10.4324/9781315166728-2

Hall, M. L., Eigsti, I. M., Bortfeld, H., and Lillo-Martin, D. (2017a). Auditory deprivation does not impair executive function, but language deprivation might: evidence from a parent-report measure in deaf native signing children. *J. Deaf Stud. Deaf Educ.* 22, 9–21. doi: 10.1093/deafed/enw054

Hall, M. L., Hall, W. C., and Caselli, N. K. (2019). Deaf children need language, not (just) speech. *First Lang.* 39, 367–395. doi: 10.1177/0142723719834102

Hall, W. C., Levin, L. L., and Anderson, M. L. (2017b). Language deprivation syndrome: a possible neurodevelopmental disorder with sociocultural origins. *Soc. Psychiatry Psychiatr. Epidemiol.* 52, 761–776. doi: 10.1007/s00127-017-1351-7

Hartshorne, J. K., Tenenbaum, J. B., and Pinker, S. (2018). A critical period for second language acquisition: evidence from 2/3 million english speakers. *Cognition* 177, 263–277. doi: 10.1016/j.cognition.2018.04.007

Hauser, P. C., Paludneviciene, R., Riddle, W., Kurz, K. B., Emmorey, K., and Contreras, J. (2016). American sign language comprehension test: a tool for sign language researchers. *J. Deaf Stud. Deaf Educ.* 21, 64–69. doi: 10.1093/deafed/env051

Hecht, J. L. (2020). Responsibility in the current epidemic of language deprivation (1990-present). *Matern. Child Health J.* 24, 1319–1322. doi: 10.1007/s10995-020-02989-1

Henner, J., and Robinson, O. (2021). *Unsettling Languages, Unruly Bodyminds: Imaging a Crip Linguistics*. Available online at: https://psyarxiv.com/7bzaw (accessed February 28, 2022).

Hildebrandt, U., and Corina, D. (2002). Phonological similarity in American Sign Language. *Lang. Cogn. Process.* 17, 593–612. doi: 10.1080/01690960143000371

Hollak, J., and Jagodziński, T. (1879). *Słownik mimiczny dla głuchoniemych i osób z nimi styczność mających*. Warszawa: Instytut Głuchoniemych i Ociemniałych.

Kegl, J. (2018). "Signed language acquisition: input," in *The Handbook of Psycholinguistics*, eds E. M. Fernández and H. S. Cairns (Hoboken, NJ: Wiley Blackwell), 674–704. doi: 10.1002/9781118829516.ch30

Kotowicz, J., Woll, B., and Herman, R. (2021). Adaptation of the british sign language receptive skills test into polish sign language. *Lang. Test.* 38, 132–153. doi: 10.1177/0265532220924598

Koulidobrova, E., and Pichler, C. (2021). Cripping the "delay": multilingualism-related consequences of re-labeling language deprivation systems. *Front. Commun.* 6:751457. doi: 10.3389/fcomm.2021.751457

Krebs, J., Roehm, D., Wilbur, R. B., and Malaia, E. A. (2021). Age of sign language acquisition has lifelong effect on syntactic preferences in sign language users. *Int. J. Behav. Dev.* 45, 397–408. doi: 10.1177/0165025420958193

Kushalnagar, P., Ryan, C., Paludneviciene, R., Spellun, A., and Gulati, S. (2020). Adverse childhood communication experiences associated with an increased risk of chronic diseases in adults who are deaf. *Am. J. Prev. Med.* 59, 548–554. doi: 10.1016/j.amepre.2020.04.016

Lenneberg, E. (1967). *Biological Foundations of Language*. New York, NY: Wiley.

Lieberman, A. M., Borovsky, A., Hatrak, M., and Mayberry, R. I. (2015). Real-time processing of ASL signs: delayed first language acquisition affects organization of the mental lexicon. *J. Exp. Psychol. Learn. Mem. Cogn.* 41, 1130–1139. doi: 10.1037/xlm0000088

Mayberry, R. I. (1993). First-language acquisition after childhood differs from second-language acquisition: the case of American Sign Language. *J. Speech Hear. Res.* 36, 1258–1270. doi: 10.1044/jshr.3606.1258

Mayberry, R. I. (1995). "Mental phonology and language comprehension, or what does that sign mistake mean?," in *Language, Gesture, and Space*, eds K. Emmorey and J. S. Reilly (Hillsdalle, NJ: Lawrence Erlbaum Associates), 355–370.

Mayberry, R. I. (2010). "Early language acquisition and adult language ability. what sign language reveals about the critical period for language," in *The Oxford Handbook of Deaf Studies, Language, and Education*, 2, eds M. Marschark and P. E. Spencer (Oxford: Oxford University Press), 281–291.

Mayberry, R. I., Chen, J. K., Witcher, P., and Klein, D. (2011). Age of acquisition effects on the functional organization of language in the adult brain. *Brain Lang.* 119, 16–29. doi: 10.1016/j.bandl.2011.05.007

Mayberry, R. I., and Eichen, E. (1991). The long-lasting advantage of learning sign language in childhood: Another look at the critical period for language acquisition. *J. Mem. Lang.* 30, 486–512. doi: 10.1016/0749-596X(91)90018-F

Mayberry, R. I., and Fischer, S. D. (1989). Looking through phonological shape to lexical meaning: the bottleneck of non-native sign language processing. *Mem. Cognit.* 17, 740–754. doi: 10.3758/BF03202635

Mayberry, R. I., and Kluender, R. (2018). Rethinking the critical period for language: new insights into an old question from American Sign Language. *Biling.* 21, 886–905. doi: 10.1017/S1366728917000724

Morford, J. P. (2003). Grammatical development in adolescent first language learners. *Linguistics* 41, 681–721. doi: 10.1515/ling.2003.022

Morford, J. P., and Carlson, M. L. (2011). Sign perception and recognition in non-native signers of ASL. *Lang. Learn. Dev.* 7, 149–168. doi: 10.1080/15475441.2011.543393

Morford, J. P., Grieve-Smith, A. B., MacFarlane, J., Staley, J., and Waters, G. S. (2008). Effects of language experience on the perception of American Sign Language. *Cognition* 109, 41–53. doi: 10.1016/j.cognition.2008.07.016

Morford, J. P., and Hänel-Faulhaber, B. (2011). Homesigners as late learners: connecting the dots from delayed acquisition in childhood to sign language processing in adulthood. *Linguist. Lang. Compass* 5, 525–537. doi: 10.1111/j.1749-818X.2011.00296.x

Morford, J. P., and Kegl, J. A. (2000). "Gestural precursors to linguistic constructs: how input shapes the form of language," in *Language and Gesture*, ed. D. McNeill (New York, NY: Cambridge University Press), 358–387. doi: 10.1017/cbo9780511620850.022

Morford, J. P., and Mayberry, R. I. (2000). "A reexamination of "early exposure" and its implications for language acquisition by eye," in *Language Acquisition by Eye*, eds C. Chamberlain, J. P. Morford, and R. I. Mayberry (Mahwah, NJ: Lawrence Erlbaum Associates), 111–127.

Newport, E. L. (1990). Maturational constraints on language learning. *Cogn. Sci.* 14, 11–28. doi: 10.1207/s15516709cog1401_2

Orfanidou, E., Adam, R., McQueen, J. M., and Morgan, G. (2009). Making sense of nonsense in British Sign Language (BSL): the contribution of different phonological parameters to sign recognition. *Mem. Cognit.* 37, 302–315. doi: 10.3758/MC.37.3.302

Penfield, W., and Roberts, L. (1959). *Speech and Brain Mechanisms*. Princeton, NJ: Princeton University Press.

Reh, R. K., Dias, B. G., Nelson, C. A. III, Kaufer, D., Werker, J. F., Kolb, B., et al. (2020). Critical period regulation across multiple timescales. *PNAS. Proc. Natl. Acad. Sci. U.S.A.* 117, 23242–23251. doi: 10.1073/pnas.1820836117

Rutkowski, P., Kuder, A., Czajkowska-Kisil, M., and Łacheta, J. (2015). The structure of nominal constructions in Polish Sign Language (PJM): a corpus-based study. *Stud. Pol. Ling.* 10, 1–15. doi: 10.4467/23005920SPL.15.001.3228

Rutkowski, P., Kuder, A., Filipczak, J., Mostowski, P., Łacheta, J., and Łozińska, S. (2017). "The design and compilation of the Polish Sign Language (PJM) Corpus," in *Different Faces of Sign Language Research*, ed. P. Rutkowski (Warsaw: University of Warsaw, Faculty of Polish Studies), 125–151.

Rutkowski, P., and Sak, M. (2016). "Sign language: eastern europe," in *The SAGE Deaf Studies Encyclopedia*, eds G. Gertz and P. Boudreault (Thousand Oaks, CA: SAGE Publications), 797–798.

Sandler, W., and Lillo-Martin, D. (2006). *Sign Language and Linguistics Universals*. New York, NY: Cambridge University Press.

Schönström, K., and Hauser, P. (2022). The sentence repetition task as a measure of sign language proficiency. *Appl. Psycholinguist.* 43, 157–175. doi: 10.1017/S0142716421000436

Siple, P., Fischer, S. D., and Bellugi, U. (1977). Memory for nonsemantic attributes of American Sign Language signs and English words. *J. Verb. Learn. Verb. Behav.* 16, 561–574. doi: 10.1016/S0022-5371(77)80019-4

Slik, F., van der, Schepens, J., Bongaerts, T., and van Hout, R. (2021). Critical period claim revisited: Re-analysis of Hartshorne, Tenenbaum, and Pinker (2018) suggests steady decline and learner-type differences. *Lang. Learn.* 72, 87–112. doi: 10.1111/lang.12470

Stokoe, W. C. (1978). *Sign Language Structure: an Outline of the Visual Communication Systems of the American Deaf (Studies in Linguistics, Occasional Papers: 8) Revised Edition*. Silver Spring, MD: Linstok Press.

Tazbirówna, W. (1950). Uwagi o języku miganym wychowanków Instytutu Głuchoniemych i Ociemniałych w Warszawie. *Poradnik Językowy* 5, 12–18.

Tomaszewski, P. (2003). *Formalna i funkcjonalna analiza zachowań językowych i niewerbalnych dziecka głuchego: Studium psycholingwistyczne.* Ph.D. dissertation. Warsaw: Institute of Psychology, Polish Academy of Sciences.

Tomaszewski, P. (2010). *Fonologia Wizualna Polskiego Języka Migowego*. Warszawa: Matrix.

Tomaszewski, P. (2011). "Lingwistyczny opis struktury polskiego języka migowego," in *Język jako Przedmiot Badań Psychologicznych, Tom 1*, eds I. Kurcz and H. Okuniewska (Warszawa: Wydawnictwo SWPS Academica), 184–238.

Tomaszewski, P. (2015). Constraints on negative prefixation in Polish Sign Language. *PLoS One* 10:e0143574. doi: 10.1371/journal.pone.0143574

Tomaszewski, P., and Eźlakowski, W. (2021a). Negative affixation in Polish Sign Language. *Sign Lang. Stud.* 21, 290–332. doi: 10.1353/sls.2021.0001

Tomaszewski, P., and Eźlakowski, W. (2021b). Temporal affixation in Polish Sign Language. *Sign Lang. Stud.* 22, 106–130. doi: 10.1353/sls.2021.0016

Tomaszewski, P., and Farris, M. (2010). "Not by the hands alone: functions of non-manual features in Polish Sign Language," in *Studies in the Psychology of Language and Communication*, ed. B. Bokus (Warszawa: Matrix), 289–320.

Tomaszewski, P., Krzysztofiak, P., Morford, J. P., and Ezlakowski, W. (2022). *Effects of Age-of-Acquisition on Proficiency in Polish Sign Language: Insights to the Critical Period Hypothesis*. Open Science Framework. Available online at: https://osf.io/pw2c9/ (accessed April 16, 2022).

Tomaszewski, P., and Piekot, T. (2015). Język migowy w perspektywie socjolingwistycznej. *Socjolingwistyka* 29, 63–87. doi: 10.17651/SOCJOLING.29.4

Tomaszewski, P., and Sak, M. (2014). "Is it possible to educate deaf children bilingually in Poland?," in *Zweisprachigkeit und bilingualer Unterricht*, eds M. Olpińska-Szkiełko and L. Bertelle (Frankfurt: Peter Lang), 129–149.

Trębicka-Postrzygacz, B. (2011). *Szkoły dla dzieci niesłyszących na ziemiach polskich w latach 1817-1914*. Lublin: Towarzystwo Naukowe KUL.

Wilkinson, E., and Morford, J. P. (2020). How bilingualism contributes to healthy development in deaf children: a public health perspective. *Matern. Child Health J.* 24, 1330–1338. doi: 10.1007/s10995-020-02976-6

Wiśniewska-Jankowska, A. (2016). Test do Oceny Znajomości Polskiego Języka Migowego – konstrukcja i charakterystyka psychometryczna. *Studia Psychol.* 54, 17–29. doi: 10.2478/V1067-010-0148-6

Wojda, P. (2010). "Transmission of Polish sign systems," in *Sign languages*, ed. D. Brentari (Cambridge: Cambridge University Press), 131–147. doi: 10.1017/cbo9780511712203.008

Woll, B. (2018). The consequences of very late exposure to BSL as an L1. *Biling.* 21, 936–937. doi: 10.1017/S1366728918000238

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# L2M1 and L2M2 Acquisition of Sign Lexicon: The Impact of Multimodality on the Sign Second Language Acquisition

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In second language research, the concept of cross-linguistic influence or transfer has frequently been used to describe the interaction between the first language (L1) and second language (L2) in the L2 acquisition process. However, less is known about the L2 acquisition of a sign language in general and specifically the differences in the acquisition process of L2M2 learners (learners learning a sign language for the first time) and L2M1 learners (signers learning another sign language) from a multimodal perspective. Our study explores the influence of modality knowledge on learning Swedish Sign Language through a descriptive analysis of the sign lexicon in narratives produced by L2M1 and L2M2 learners, respectively. A descriptive mixed-methods framework was used to analyze narratives of adult L2M1 ($n$ = 9) and L2M2 learners ($n$ = 15), with a focus on sign lexicon, i.e., use and distribution of the sign types such as lexical signs, depicting signs (classifier predicates), fingerspelling, pointing, and gestures. The number and distribution of the signs are later compared between the groups. In addition, a comparison with a control group consisting of L1 signers ($n$ = 9) is provided. The results suggest that L2M2 learners exhibit cross-modal cross-linguistic transfer from Swedish (through higher usage of lexical signs and fingerspelling). L2M1 learners exhibits same-modal cross-linguistic transfer from L1 sign languages (through higher usage of depicting signs and use of signs from L1 sign language and international signs). The study suggests that it is harder for L2M2 learners to acquire the modality-specific lexicon, despite possible underlying gestural knowledge. Furthermore, the study suggests that L2M1 learners' access to modality-specific knowledge, overlapping access to gestural knowledge and iconicity, facilitates faster L2 lexical acquisition, which is discussed from the perspective of linguistic relativity (including modality) and its role in sign L2 acquisition.

**Keywords: sign language (SL), second language (L2) acquisition, multimodality, lexicon, cross-linguistic influence (CLI), transfer**



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## INTRODUCTION

Our current knowledge of sign second language acquisition is mainly informed by research involving second language (L2) learning of a sign language in a second modality (M2), i.e., it is based mainly on research on hearing adult learners with a spoken language as a first language (L1) who are learning a sign language as an L2 using a different modality. However, knowledge about the same modality (M1) learning of a sign language, i.e., deaf adult learners with an L1 sign language learning a new L2 sign language, is scarce, particularly regarding the acquisition of linguistic structures. Therefore, this study attempts to fill this knowledge gap by looking at sign acquisition in deaf L1 signers learning a new sign language as an L2, namely, Swedish Sign Language (*Svenskt teckenspråk*, STS), and comparing it with the L2 learning of hearing L2 learners of STS. We focused on both L2M1 and L2M2 signers, which are referred to as M1 and M2 signers for ease of reading, as the overall framing of this study is second language acquisition.

One important area of second language acquisition (SLA) is the concept of cross-linguistic influence (CLI) or transfer. This research has shown us that language learners seem to transfer previous language knowledge to another language. The concept and the characteristics of this transfer between the languages among multilingual learners have been widely discussed in the literature (Jarvis and Pavlenko, 2008). For sign languages, earlier research has pointed out the influence of gestural knowledge and iconicity on acquiring a sign language among M2 learners (e.g., Taub et al., 2008; Ortega, 2017; Ortega et al., 2019). However, less is known about the M1 acquisition of a sign language in general and specifically the differences in the acquisition process of M1 learners and M2 learners. This article seeks to contribute to this field.

We aimed to examine how prior modality knowledge influences learning STS as an L2 through a descriptive study of the sign lexicon in retold narratives produced by M1 and M2 learners. With CLI as a framework, we aimed to describe the degree and types of transfer on L2 STS as the recipient language depending on the learners' source languages (L1/Ln), to understand the effect of multimodality and its role for L2 acquisition. The "Introduction" section of this article describes the sign language lexicon from the perspective of STS. The next section, "Sign Second Language Acquisition (SSLA)," summarizes the core body of research relevant to the scope of this study, including the concept of CLI and previous research on Sign L2 acquisition, which is followed by the "Materials and Methods" section. Finally, results and discussion are presented.

## SIGN LANGUAGE LEXICON

While many sign languages share similar properties, sign linguistics literature contains different theoretical descriptions and classifications pertaining to a variety of sign categories. Thus, the categories have been labeled differently in the sign language literature, depending on their form, meaning, and degree of lexicalization and conventionalism. In our description, we departed from the study's language, STS. We also attempted to adopt a non-theory-bounded and descriptive approach to describe the sign categories. A sign can be seen to be equivalent to the traditional concept and definition of a word, although there are alternative views on this (e.g., Lepic, 2019). Some researchers suggest that the signed modality (in comparison with the spoken modality) allows for some modality-dependent characteristics, affecting the linguistic structure (e.g., Meier (2002)). First, the nature of signed modality with using manual components (i.e., the hands) and the non-manual components (i.e., facial expressions and body movement) allows for a higher degree of simultaneity in production and for the visual perception of the information. Second, there is the possibility of using the space in the front of the signer to create meaning and reference, and it affects, for example, the lexicon. From a phonological view, Brentari and Padden (2001) described a model of sign language lexicon as three components based on the forms of the signs, i.e., divided into *non-native* (or foreign) and *native* signs. The native signs category is, in turn, divided into a *core lexicon* and a *spatial lexicon*. The non-native lexicon is formed based on the manual alphabet, e.g., fingerspelling. The core lexicon includes signs that are lexical and conventionalized and typically included in a sign language dictionary, e.g., lexical signs. The spatial lexicon includes signs that are partly conventionalized in form. The use of spatial lexical items requires context to be fully understood, e.g., depicting signs [also labeled as, e.g., classifier predicates, polycomponential signs, and depicting constructions in the literature (e.g., Liddell, 2003; Schembri, 2003; Cormier et al., 2012 for comprehensive overviews)]. On a somewhat similar matter, Johnston and Schembri (2010) (also refer to Johnston and Ferrara, 2012; Hodge and Johnston, 2014) divided the sign lexicon into three components based on their degree of lexicalization: *lexical*, *partly lexical,* and *non-lexical*. Lexical signs correspond to the signs that can be said to be most conventionalized in form and meaning and equivalent to the notion of the "word" in spoken languages and that are listed in dictionaries, e.g., the STS dictionary. Partly lexical signs are signs that are partly conventionalized in form and meaning. Those signs often require context to be understood. Lexical signs include depicting signs and pointing. Finally, non-lexical signs are signs that are at least conventionalized in form and meaning. In this study, gestures and other manual or non-manual acts are included, e.g., they vary widely in form and meaning and are highly dependent on contextualization.

We will now define the sign categories that we have considered in this study: lexical signs, fingerspelling, pointing, depicting signs, and gestures.

*Lexical signs* are the signs that can be found in the STS dictionary, i.e., "frozen signs" that are conventionalized in form and meaning. STS dictionary work has been conducted since the 1990s at Stockholm University and consists today of approximately 20,000 recorded and officially published signs. The lexical signs in the dictionary have been collected through observations of signs used in the deaf community (through, i.e., social media), the media (TV broadcasts in sign language), and signs found in the Swedish Sign Language Corpus. This large STS dictionary has provided us with a source to consult in order to ensure that the signs we identified in this study can be considered lexical signs. Often these signs are accompanied by a specific mouth action that can be either sign language-based (i.e., mouth gestures) or borrowed from Swedish (mouthing) (e.g., Crasborn et al., 2008; Mesch et al., 2021 for closer descriptions of mouth actions in sign languages and STS). In STS, mouthing is a frequent mouth action category, especially functional, and is used to distinguish between ambiguous lexical signs, i.e., manual sign homonyms.

*Fingerspelling* is an alternative usage to lexical signs and comes in two different formats. First, *full fingerspelling* is especially used to express names and concepts and to borrow words from spoken languages (not only Swedish). Full fingerspelling does not follow the standard phonological configuration of a sign (e.g., in the parameters of handshape, movement, location, and orientation). Then, there is *lexicalized fingerspelling*, where the sign has its origin in fingerspelling but has been reduced and conformed closer to the standard phonological formation of a lexical sign (cf. Battison, 1978, on fingerspelled words).

*Depicting signs* include signs not listed in the STS dictionary and have been called multimorphemic constructions (e.g., Wallin, 1996, in terms of "polysynthetic signs"), whose form and meaning depend on contextualization. Handshape types are a key component consistently reported in the literature on depicting signs and are used to describe such signs. As in earlier accounts using this type of data (e.g., Schönström and Mesch, 2019), we departed from three main categories of handshape units: entity, handle, and descriptor in order to be able to identify the depicting signs in our data, and the representation of the movement that can be linked to the main categories of movement or existing. This category may fall within the frame of morphosyntax, but in our presentation we have treated this category as part of STS lexicon, departing from a broader application of the use of signs.

*Pointing* is another category of sign that is a recurring component of many sign languages and is primarily linked to the use of the INDEX hand. Its physical form is simply pointing toward different locations or at different objects. But in sign languages, pointing is more refined and part of the sign lexicon, often functioning as pronouns (e.g., Cormier et al., 2013). Its meaning depends on the location in the signing space to where the sign points. It can be considered a partly lexical sign.

As *gestures*, we have counted such acts that vary widely in form and meaning and are not part of any categories described above, such as palm-up gestures and "come here" gestures.

Frequency is essential when studying sign categories in narratives (e.g., Johnston, 2012). By analyzing how often different sign categories appear in the study data, we can learn how common one category is in comparison with other categories. Analyzing frequency also allows us to see if there are differences between different signers, such as L1, M1, and M2 signers. For example, L1 data can inform us about how common it is to use lexical signs and depicting signs in narratives and thus tell us how M1 and M2 signers relate to these data.

## SIGN SECOND LANGUAGE ACQUISITION (SSLA)

Although research on SSLA is a growing field of interest among scholars, most of the research to date has focused on M2 adult learners, i.e., primarily hearing adults with an L1 spoken language that is learning a sign language as an L2 (e.g., Schönström, 2021). There are few studies of M1 learners, i.e., primarily deaf adults with an L1 sign language learning another sign language as an L2. We have not found any study on the acquisition of sign lexicon among M1 signers except for a study by Koulidobrova (2019), who studied argument omission in M1 signers.

It is essential to consider the modality effect for the two groups of learners; M2 learners have to learn to express language in a totally different way than previously, while M1 learners already have the skills to express themselves through the visual-gestural modality. With this in mind, it is necessary to understand that the SSLA process can be partly different, depending on whether the learners are M1 or M2 learners.

Not only do M2 learners have to learn the sign language itself but they must also learn how to express the language. According to Woll (2013), learners may experience difficulties adapting the visual-gestural modality, i.e., using the body, facial expressions, gaze, etc., to produce language. Other features may also impact their learning. For example, they already have motoric skills in their fingers, hands, and arms, but they must learn how to use them to express signs with correct phonology. Another new learning feature is non-manual grammar expressed through, e.g., moving eyebrows. The learners already use these movements in their daily life. However, when learning a sign language, they need to understand the movements as grammatical markers and learn to use them correctly. The same applies to the use of gestures. Speakers of a spoken language often use gestures in different ways. Sometimes, these gestures appear together with speech, co-speech gestures, and sometimes, they are used to complement or replace speech (Özyürek, 2012). Several studies have suggested that such gestural knowledge used in spoken languages can be beneficial for M2 learners' acquisition of sign languages (Casey and Emmorey, 2009; Chen-Pichler and Koulidobrova, 2015; Ortega et al., 2019; Marshall et al., 2021).

An apparent feature in sign languages is that a considerable number of signs are highly iconic, meaning that the formations of signs correspond to or are transparent representations of the form, shape, or action of reality, i.e., a ball's form or the action of carrying a bag. Ortega and Morgan (2015a,b) found iconicity to have both advantages and disadvantages for M2 learners of British Sign Language (BSL). The advantages were that it was easier for the learners to understand and memorize the signs by connecting them to reality (cf. Baus et al., 2012). Simultaneously, the iconicity led the learners to fail to note how the sign is performed correctly phonologically, presumably because they find the signs "easy." Thus, the iconicity may cause disadvantages. When comparing a range of different studies on the iconicity impact on sign L2 learning, Ortega (2017) confirmed that iconicity has both positive and negative impacts on learning. His compilation shows that iconicity seems to positively affect the sign's conceptual-semantic feature but not its linguistic structure.

A cross-sectional study by Schönström and Mesch (2019) investigated the development of depicting sign use of M2 signers with deaf L1 signers as a benchmark. Their results revealed that M2 signers tend to stick to lexical signs rather than depicting signs compared with L1 signers, but that the proportion of depicting signs grows with acquired sign proficiency and experience. In addition, the M2 signers exhibit the use of depicting signs early on, which confirms previous results on M2 learning of depicting signs as reported by

Marshall and Morgan (2015) for BSL and by Boers-Visker (2020) for Dutch Sign Language (NGT).

The spatial structure of sign languages is another characteristic that the research body has identified as difficult to acquire for M2 learners (e.g., McKee and McKee, 1992; Ferrara and Nilsson, 2017; Shield and Meier, 2018; Boers-Visker, 2020; Gulamani et al., 2020). The space in front of the body can be used in a range of ways, not only for articulating lexical signs but also for grammatical and discourse purposes (Perniss, 2012; Boers-Visker, 2020). Such use of the space is initially unfamiliar for new signers who initially do not know that there is a signing space in front of their body. Ferrara and Nilsson (2017) found in their study that M2 learners of Norwegian Sign Language struggled to use the signing space and instead relied on lexical signs, i.e., the learners chose a familiar, sequential strategy with one lexical sign after another, rather than the unfamiliar spatial strategy that places the sign in a specific location or direction.

As M2 signers are often initially unfamiliar with the use of face and body to express language, sign language instruction often includes modality-specific training (Holmström, 2019, 2021, also refer to McKee and McKee, 1992). Holmström (2019) found that teaching a university STS beginners' course largely consisted of modality-specific metalinguistic information. For example, the teachers told the students about the differences between spoken and sign languages in expression, perception, and grammar. In addition, the teacher made them aware that the view of signs differs for the signer and the addressee. In a follow-up study, Holmström (2021) further examined STS teaching and found that during the initial stage of their learning, students were particularly trained to make and keep eye contact, get attention, and use visual turn-taking. She also found that a large amount of the teaching consisted of exercises in learning and using iconicity, spatiality, and simultaneity in STS. The students in this study said that they initially found the exercises very strange, but gradually, they made them more comfortable expressing language with face and body. This indicates that M2 learners benefit from modality-specific training to develop their L2 and move away from the linear and lexical production into a more spatial one, with depicting signs and constructed action.

## Transfer/Cross-Linguistic Influence

In comparison with SSLA, there is a vast body of SLA research on spoken language from a wide range of perspectives. An important topic of SLA research has been the study of transfer or cross-linguistic influence (CLI) and its role in L2 acquisition, and there is an extensive body of research on CLI in the SLA literature (for reviews, refer to Odlin, 1989; Jarvis and Pavlenko, 2008). CLI can be defined as the influence of an L2 learner's prior knowledge of one or more languages on the processing and use of the new language. Typically, CLI research seeks to answer the question of how prior knowledge of one or more languages shapes learning a new language. *Transfer* is one common concept of outcome in CLI. According to Odlin (1989), a transfer is seen as a result of the influence based on the similarities and differences between the target language (i.e., the L2) and the other previously acquired language. Typically, as regards directionality, it has been studied under the framing of the influence of L1 on L2 learning (i.e., *forward transfer*). However, more recent studies have also included perspectives on the influence of L2 knowledge on learning additional languages (L3, L4, etc.) (i.e., *lateral transfer*). Furthermore, studies have suggested that learners can transfer knowledge from an L2 to L1 (i.e., *reverse transfer*) (Jarvis and Pavlenko, 2008).

One of the main factors influencing the degree of CLI is the learner's perceived cross-linguistic similarity between the languages (i.e., the L1 and the L2). CLI is more likely to happen when the learner perceives a similarity between the L1 and the L2 rather than when the learner perceives the languages as different. Ringbom (2007) suggested that cross-linguistic similarity facilitates learning of the new language as it gives the learners the ability to link words and/or structures to other similar words or structures. Furthermore, Ringbom claimed that linguistic and typological distance between the languages (i.e., the L1 and the L2), i.e., linguistic relativity, plays an essential role in the CLI processes. Researchers have found and discussed different types of transfer. The earliest accounts of transfer focused on errors in the target language caused by transfer, i.e., *interference* or negative transfer. However, later research has pointed out that the ultimate outcomes of CLI are often positive. Moreover, learners' perceived assumptions about the similarities and/or differences between source and recipient languages can lead to underproduction or overproduction of structures in the recipient language.

Previous CLI research has shown that transfer can occur in several linguistic areas (e.g., phonology, vocabulary, and syntax). Moreover, it can also be manifested in more cognitive matters, i.e., through the learners' knowledge of how different meanings or concepts are expressed (e.g., time and location). Furthermore, Jarvis and Pavlenko suggested a ten-dimensional model of CLI types based on its characteristics, i.e., (a) areas of language knowledge, (b) directionality, (c) cognitive level, (d) type of knowledge, (e) intentionality, (f) mode, (g) channel, (h) form, (i) manifestation, and (j) outcome (Jarvis and Pavlenko, 2008, p. 20ff).

Even within SSLA research, CLI has been a subject of interest for several researchers. Some researchers have pointed out limited possibilities of a "physical" transfer between a spoken and sign language, at least with regard to phonology (Rosen, 2004; Bochner et al., 2011; Ortega and Morgan, 2015a,b). However, Chen Pichler (2010) suggested a more abstract treatment of the notion of phonology, allowing for an analysis of the previous gesture skills in M2 learners and its influence on L2 ASL phonology. Chen Pichler found instances of unmarked handshapes in L2 ASL, where marked handshapes were target forms, and suggested that erroneous use of unmarked handshapes was a result of transfer from M2 learners' gestural knowledge, affecting ASL phonology. Furthermore, as described above, Ortega and Morgan (2015a,b) and Ortega et al. (2019) suggested that there are effects of transfer on BSL phonology originated in the learners' prior knowledge of gesture and concepts linked to iconicity. As a result, this prior knowledge leads to positive and negative effects on BSL phonology. Ortega et al. (2019) suggested this to be explained in terms of manual cognates, i.e., there is a perceived similarity between the gestures and signs, which is scaffolding the learners' learning of the sign lexicon. Furthermore, the development of spatio-visual skills in M2 ASL learners has been studied by Taub et al. (2008), who examined the use of classifier structures (i.e., depicting signs) (in third-person discourse structures), constructed action (in first-person discourse structures), and location in signing space. As the use of gestures has been shown to have an important role in spoken languages and its use of the spatial domain, Taub et al. (2008) suggested that there is a possibility that some previous spatio-visual knowledge in the source language, for example, the knowledge of using direct speech/constructed dialog, could be transferred to L2 ASL. However, they found no such transfer patterns regarding first-person discourse (i.e., the use of constructed action), but some transfer patterns regarding third-person discourse (i.e., the use of classifier structures) and on the use of spatial location structures. Taub et al. (2008) suggested that ASL learners focus on vocabulary items (which inhibit the use of constructed actions) and transfer the use of iconic co-speech gestures into classifier-like structures and that preexisting skills in using location in gesture are transferred to the use of location in the signing space in L2 ASL. In a corpus-based study on the use of mouth actions in M2 learners, Mesch and Schönström (2021) compared the use of mouth actions in M2 learners and L1 signers of STS. They found an overproduction of the mouthing category of mouth actions (i.e., borrowed-in mouthing of Swedish) in M2 learners, suggesting that it was an effect of transfer from L1 Swedish into L2 STS.

When combined, our current but limited knowledge about CLI in SSLA has been limited to M2 learners. To broaden our understanding of CLI in SSLA, a study involving both M1 and M2 learners would be fruitful. Our working hypothesis is that M1 learners encounter the learning of iconic and spatio-visual skills positively compared with M2 learners due to cross-linguistic and modality similarity. M2 learners encounter a challenge when learning such structures, and furthermore, M2 learners approach the learning of non-spatial lexicon (e.g., lexical signs and fingerspelling) differently to M1 learners due to the perceived structural similarity to words of L1 Swedish. This will have different outcomes in the produced sign lexicon between the learner groups due to different CLI sources in their processing and use of L2 STS.

## MATERIALS AND METHODS

Using a descriptive mixed-methods framework, 24 narratives from adult M1 ($n$ = 9) and M2 ($n$ = 15) learners were analyzed. This study uses data from two research projects focusing on adult L2 learners. The first one is the ongoing project Mulder (the multilingual situation of deaf refugees in Sweden) with a focus on deaf M1 learners. For project Mulder, data were collected at four folk high schools (independent adult education colleges) with programs for deaf migrants learning STS and Swedish. The second is the previous project TATE (Från tal till tecken–att lära sig Svenskt teckenspråk som andraspråk [From speech to sign–learning Swedish Sign Language as a second language]), focusing on hearing M2 learners. Within the project TATE, an STS as L2 corpus was constructed comprising data from M2 learners (Schönström and Mesch, 2017).

In both projects, the participants performed an elicitation task consisting of a short clip from the movie "The Plank." Two men struggle to carry a plank through an urban area in the minute-long clip. The main event involves the plank going through a window into a bar, causing a glass of beer to fall out into a bucket outside the bar. A misunderstanding then arises between the window cleaner and the person whose beer it is. This clip was chosen to elicit linguistic constructions related to depicting signs and constructed actions, as well as spatial constructions. In project TATE, deaf L1 signers were recruited to perform the same task and create a control group to compare with the M2 signers. The data from Mulder and the STS as L2 corpus allow us in this study to compare narratives from M1 and M2 signers, as well as L1 signers.

The narratives were transcribed using ELAN and coded by sign type. A transcription protocol developed by Wallin and Mesch (2018) was used in the annotation work. Also, a further developed protocol for L2 analysis (Mesch and Schönström, 2018) was used. This included transcription through a controlled vocabulary list, including information about sign types associated with every sign in the list (lexical sign, pointing, depicting sign, fingerspelling). The manual signing was transcribed concerning using the dominant hand and non-dominant hand representing the sign glosses. Transcription of the sign language data is, in general, time-consuming. However, thanks to the available STS L2 corpus comprising M2 data, we were able to compare our new M1 data obtained within the Mulder project with the M2 data from the corpus. Several people have contributed to the manual transcription work of the sign language data. All coders have been deaf native STS users and students in sign linguistics or senior sign linguistic researchers. For the STS as L2 corpus data (M2 data), deaf research assistants were hired to code the sign glosses with the project team (of which the first author was part). The transcription was later controlled by a deaf senior researcher of the team. For the Mulder project (M1 data), the same procedure was applied. A deaf sign linguistic student coded the signs together with the first author of this study. However, no inter-rater reliability data are available. Instead, the work with the coding is integrated into a teamwork style with discussions within the team. The first author also controlled all the coding in order to ensure consistency. In the next step, the frequencies and distribution of the signs were categorized by gloss and sign types (**Table 1**).

Furthermore, we also created a row for the qualitative analysis of instances of CLI for the M1 data, i.e., the negative transfers. Our analysis was limited to the use of signs. The analysis of the negative transfers was explorative, i.e., the authors of the study, both deaf and fluent in STS, analyzed the narratives of the signers and identified instances of what we interpreted as negative transfer and coded them as (1) mouth transfer, (2) lexical transfer, and (3) handshape transfer (refer to the "Instances of cross-linguistic influence (CLI) in M1 and M2 signers" section for further description of the analysis and result).

**TABLE 1 |** Coding of sign type categories.

| Sign type | Sub-category | Example |
|---|---|---|
| Lexical signs | STS signs | POLICE "police" |
| | International/Ln signs | DRINK@it "drink" |
| Depicting signs | Entity | ENTITY[handshape]+MOVE "movement of an entity" |
| | Handle | GRIP[handshape] +HANDLE "handle with grip (of an entity)" |
| | Descriptor | SIZE[handshape] +SPECIFY "size and shape specifying" |
| Pointing | | INDEX "pointing to self" |
| Fingerspelling | | ÖL@b "beer" |
| Gesture | | HAND-WAVE@g "wave with hands" |

## Participants

Project Mulder recruited data from a considerable number of M1 signers, but to make the comparisons as equal as possible with the M2 learners we restricted our group to nine M1 signers, i.e., five male signers and four female signers, $M_{age}$ = 36.7 years, $SD$ = 4.6, range 30–45 years. All nine participants were born into deaf families and have acquired a sign language from birth. They also have a fundamental educational background, i.e., they have undergone at least elementary school, and most of them have also undergone some kind of secondary school level. **Table 2** shows the participants' background data. We also conducted a non-verbal cognitive test, Kaufmann Brief Intelligence Test, Second Edition (KBIT-2; Kaufman and Kaufman, 2004), which revealed that the nine participants' IQ profiles are average. All participants were recruited through the four folk high schools, and most of them had been enrolled at the schools for around 3–7 months.

Data from the M2 participants were obtained from the STS as L2 corpus. All participants are hearing adults with Swedish as L1 and attend a sign language interpreting program at the university level. None of the participants had learned a sign language before enrollment. As the STS as the L2 corpus is longitudinal, we decided to depart from data from a group that has studied sign language for approximately 5–6 months as the M1 participants had learned STS for approximately 3–7 months (with one exception of one who has been in Sweden for 5 years). The group of M2 learners consists of 15 students: 2 male students and 13 female students, $M_{age}$ = 23.9 years, $SD$ = 5.1, range 19–40 years.

As a control group, data from L1 signers, one male student and eight female students, $M_{age}$ = 27.6 years, $SD$ = 11.22, range 20–50 years, were obtained from the STS as L2 corpus.

**TABLE 2 |** M1 participants in the study.

| ID | Gender | Age | L1 | Years of schooling | Length in Sweden at data collection |
|---|---|---|---|---|---|
| 203 | Female | 40 | Iranian SL | 12 | 6 months |
| 205 | Male | 30 | Italian SL | 15 | 6 months |
| 206 | Male | 31 | Lithuanian SL | 11 | 6 months |
| 207 | Female | 45 | Latvian SL | 12 | 5 years |
| 210 | Female | 37 | Polish SL | 15 | 3 months |
| 211 | Male | 36 | Polish SL | 12 | 3 months |
| 212 | Male | 39 | Polish SL | 12 | 3 months |
| 213 | Male | 38 | Polish SL | 14 | 3 months |
| 306 | Female | 34 | Russian SL | 10 | 6–7 months |

# RESULTS

The results are presented below. First, we accounted for the frequency and distribution of signs used in the groups. Second, we accounted for instances of cross-linguistic influence found in the data.

## Frequency and Distribution of Signs

The frequency and distribution of sign categories by group are presented below. **Table 3** shows the group's frequency of signs, including mean, standard deviation, standard error, range (min–max), and 95% confidence intervals. N signs refer to the total number of glosses transcribed in the analysis. It also demonstrates the mean length of the narratives by group. This includes all the glosses, including held signs and unclear signs used in the narratives. In addition, the M1 group produced a type of sign that we have coded as foreign lexical signs, i.e., signs from other sign languages, such as their L1 or international sign. In total, we found 22 instances of foreign signs for the whole group of M1 signers, $M$ = 2.4, $SD$ = 1.7, range 0–4. No such use was observed in the L1 and M2 groups.

The last column in **Table 3** presents the distribution of the sign categories lexical signs, depicting signs (DS), fingerspelling, pointing, and gestures, in mean and percent of the total number of signs (i.e., the categories combined) by the groups M1, M2, and L1 signers. The distribution of the sign categories differs between the groups. Regarding the category of *lexical signs*, M2 signers exhibit the highest proportion (63.4%), followed by L1 signers (54.8%) and M1 signers (43.8%). M1 signers exhibit the highest proportion for the category *depicting signs*, with 41.9%, followed by L1 signers (27.3%) and M2 signers (17.9%). M2 signers have the highest proportion regarding *fingerspelling* with 9.8% followed by L1 signers and M1 signers with 7.6 and 2.6%, respectively. *Pointing* was mostly used by L1 and M1 signers with 8.6 and 9.1%, respectively, compared with M2 signers (6.0%). Finally, *gestures* were generally minimal for all the groups with 2.6, 3.0, and 1.6% for M1, M2, and L1 signers, respectively.

To determine if there are any statistically significant differences between the groups in category means, a one-way ANOVA was run. A Shapiro-Wilk's test for normality revealed that means for lexical signs and depicting signs were normally distributed, but that means for fingerspelling (violated for M1 and M2 group), pointing (violated for M2 group), and gesture (violated for M1 group) were not normally distributed. Levene's test for equality of variances confirmed the assumptions of homogeneity of variances for the

**TABLE 3 |** Mean frequency and distribution of signs and sign categories [lexical signs, depicting signs (DS), fingerspelling, pointing, and gesture] in group level.

| | | *N* | *M* | SD | S.E. | 95% CI for M | | Min | Max | Proportion of total signs |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Lower | Upper | | | |
| N Signs | M1 | 9 | 99.3 | 48.4 | 16.1 | 62.2 | 136.5 | 31 | 187 | |
| | M2 | 15 | 116.7 | 43.8 | 11.3 | 92.4 | 140.9 | 60 | 183 | |
| | L1 | 9 | 156.4 | 40.9 | 13.6 | 125.0 | 187.9 | 81 | 208 | |
| Lexical Signs | M1 | 9 | 35.9 | 20.3 | 6.8 | 20.3 | 51.5 | 11 | 77 | 43.8% |
| | M2 | 15 | 65.8 | 22.4 | 5.8 | 53.4 | 78.2 | 30 | 111 | 63.4% |
| | L1 | 9 | 77.4 | 25.1 | 8.4 | 58.2 | 96.7 | 39 | 114 | 54.8% |
| Depicting Signs | M1 | 9 | 34.3 | 16.2 | 5.4 | 21.9 | 46.8 | 14 | 60 | 41.9% |
| | M2 | 15 | 18.5 | 12.4 | 3.2 | 11.7 | 25.4 | 1 | 41 | 17.9% |
| | L1 | 9 | 38.7 | 11.5 | 3.8 | 29.8 | 47.5 | 21 | 55 | 27.3% |
| Fingerspelling | M1 | 9 | 2.1 | 1.7 | 0.6 | 0.8 | 3.4 | 1 | 6 | 2.6% |
| | M2 | 15 | 10.1 | 5.4 | 1.4 | 7.1 | 13.1 | 5 | 21 | 9.8% |
| | L1 | 9 | 10.8 | 4.5 | 1.5 | 7.3 | 14.3 | 6 | 20 | 7.6% |
| Pointing | M1 | 9 | 7.4 | 6.3 | 2.1 | 2.6 | 12.3 | 0 | 17 | 9.1% |
| | M2 | 15 | 6.2 | 6.4 | 1.7 | 2.6 | 9.8 | 1 | 23 | 6.0% |
| | L1 | 9 | 12.2 | 6.2 | 2.1 | 7.4 | 17.0 | 3 | 23 | 8.6% |
| Gesture | M1 | 9 | 2.1 | 2.1 | 0.7 | 0.5 | 3.8 | 0 | 7 | 2.6% |
| | M2 | 15 | 3.1 | 2.4 | 0.6 | 1.8 | 4.4 | 0 | 7 | 3.0% |
| | L1 | 9 | 2.3 | 2.0 | 0.7 | 0.8 | 3.9 | 0 | 5 | 1.6% |

following categories: lexical signs ($p$ = 0.0598), depicting signs ($p$ = 0.281), pointing ($p$ = 0.967), gesture ($p$ = 0.0570), but was violated for fingerspelling ($p$ = 0.034). Welch's ANOVA revealed that there was a statistically significant difference between the groups in lexical signs $F(2,17.301) = 8.612$, $p = 0.003$, depicting signs $F(2,16.776) = 8.555$, $p = 0.003$, and fingerspelling $F(2,16.558) = 24.333$, $p < 0.001$, but not for pointing $F(2,17.561) = 2.569$, $p = 0.105$ and gesture $F(2,18.071) = 0.672$, $p = 0.523$.

To explore the contrasts between the groups for each category, Bonferroni *post hoc* analysis was carried out on lexical signs and depicting signs. For lexical signs, the difference between M1 and M2 [−29.91, 95% CI (−54.09 to −5.73)], and M1 and L1 [−41.56, 95% CI (−68.59 to −14.52)] was statistically significant with $p = 0.011$ and $p = 0.002$, respectively, but not between L1 and M2 [11.64, 95% CI (−12.53 to 35.82), $p = 0.695$]. For depicting signs, the difference between M1 and M2 [15.80, 95% CI (1.55 to 30.05)], and L1 and M2 [20.13, 95% CI (5.88 to 34.38)] was statistically significant with $p = 0.026$ and $p = 0.004$, respectively, but not between L1 and M1 [4.33, 95 % CI (−11.60 to 20.27), $p = 1.00$]. For the category fingerspelling, Games-Howell *post hoc* analysis revealed that the difference between M1 and M2 [−8.02, 95% CI (−12.80 to −3.25)] and M1 and L1 [−8.67, 95% CI (−13.06 to −4.27)] was statistically significant with $p < 0.001$ and $p < 0.001$, respectively, but not between L1 and M2 [0.64, 95% CI (−4.57 to 5.86), $p = 0.947$].

In terms of over- and underproduction of target STS forms, the results suggest a modality effect on L2 acquisition based on the proportions of specifically sign language-specific patterns such as depicting signs and signs more closely related to spoken languages such as lexical signs and fingerspelling. It also indicates that lexical signs are under-produced among the M1 group, which we interpreted as they still are struggling with the learning of lexical signs.

Our analysis of the M1 narratives also revealed some interesting qualitative patterns that are suggested as a link to cross-linguistic influence, which will be elaborated further in the next section.

## Instances of Cross-Linguistic Influence (CLI) in M1 and M2 Signers

In our qualitative analysis of M1 data, we found interesting patterns of within-modality cross-linguistic influence. As previously mentioned, we focused on negative transfers, i.e., non-target forms of STS that we have identified as transfers from other sign languages.

Regarding the M1 learners, we identified 56 instances of negative transfers, where we then conducted a further qualitative analysis. In this study, we identified three types of transfer, namely, mouth transfer, lexical transfer, and handshape transfer. Mouth transfer is when the participants use mouth actions from other language(s) that they know (either an L1 or an Ln). For example, we observed that the learners could add mouthing from English or mouthing from their national spoken languages while producing STS. This seems to happen mostly when the target STS sign's mouthing is based on Swedish. It was not linked to the manual signing; it could either be a lexical STS sign (as in the sign ANNAN) or a lexical Ln sign (an international sign as in PEOPLE@it) (refer to the examples in **Figure 1**).

Interestingly, mouthing transfer happens primarily in combination with STS signs, i.e., the learners are signing STS but use non-target mouthing influenced by their L1 or Ln. Mouthing transfers from English were most common in this

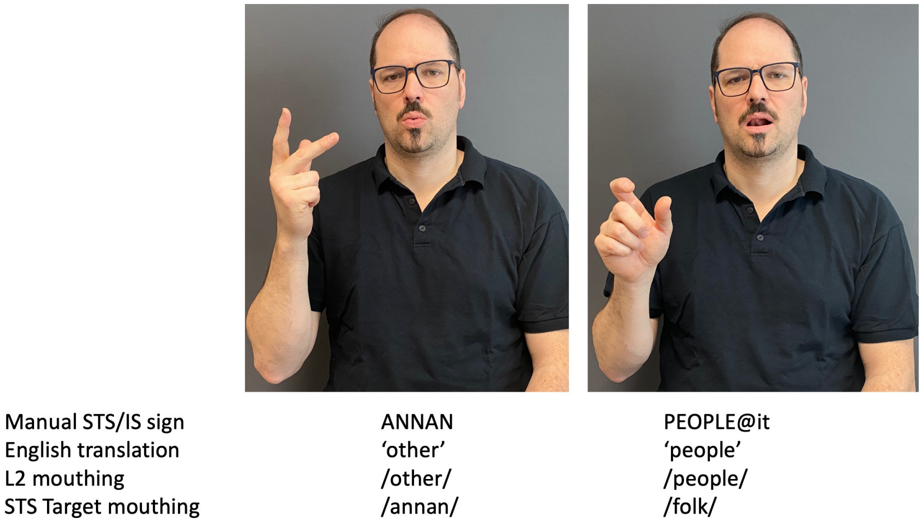


**FIGURE 1 |** Examples of mouth transfer.

type of transfer, but we also identified mouthing of the word *okno* [window] from Polish in participants 211 and 213 and the Icelandic *veit ekki* [do not know] in participant 213. The latter is particularly interesting as this participant first moved from Poland to Iceland and lived there for a few years before moving to Sweden. Thus, this mouth transfer does not come from 213's L1 but her L2. We also found that the mouthing comes together with the manual Icelandic sign VEIT EKKI [do not know]. The sign (including the mouthing) of *veit ekki* shares some similarities with the equivalent STS sign of *vet inte* [do not know] (**Figure 2**). There are similarities in the visual surface properties of the mouthing and in the phonological structure of the signs with respect to location and, to some degree, movement, even if the handshape is different.

We also observed lexical transfers, i.e., that manual signs from the learners' L2/Ln language were transferred to STS. The lexical transfers found in the data vary, but some can be identified as signs typically used in international sign contexts, such as the sign for BAR (**Figure 3A**). Other seem to be variants of signs possibly borrowed from other sign languages, for example, TREE from Lithuanian SL (**Figure 3B**) and BUILDING probably from ASL (**Figure 3C**). Due to some of the signs' depictive characteristics, highly iconic properties, and potential cross-linguistic similarities of unknown SLs, it is not always straightforward to firmly decide the origin of the signs beyond the fact that they are non-STS signs.

Finally, we also observed what we suggest is handshape transfers. Handshape transfers refer to the use of non-STS handshapes or non-target handshapes when producing a lexical or depicting sign. Handshape transfers were the least common and appeared only in two of the learners in our M1 group. For example, we observed the use of the  handshape and the  handshape referring to "drinking." Participant 306, in turn, used a handshape transfer, , from Russian Sign Language, referring to "window." These handshapes are not used in such contexts in STS, except for  for contexts where drinking from a small teacup.

There was individual variation in the CLI patterns as the participants' frequency and use of different types of transfers varied. For example, participant 210 did not transfer at all in the retellings, while 205 did more frequently with primary mouth transfers from English.

Such CLI patterns found and described above for M1 learners were not found in M2 learners. As the M2 learners have no previous knowledge of any sign language, their CLI patterns are different, i.e., no sign language source. The CLI patterns observed for M2 learners were more linked to their L1 Swedish to various degrees and possibly their gestural repertoire. For example, Mesch and Schönström (2021) on the study of mouth actions using the same M2 data, i.e., from the STS L2 corpus, reported a higher usage of mouthing in M2 learners in terms of a higher frequency of full mouthing rather than using reduced mouthing (as in L1 signers).

## DISCUSSION

The purpose of this study was to explore the role of multimodality in the acquisition of sign lexicon in two groups of learners, of which one, M1 learners, had prior knowledge of a sign language, and the other did not, i.e., are M2 learners. CLI has been used as a framework to examine patterns of CLI in the retold narratives produced by the groups. As a comparison, data from L1 signers were provided. The results revealed that the lexical distribution of M1 learners was more similar to that of L1 signers and more different from M2 learners, as M2 learners exhibit less use of depicting signs. This is in line with previous studies that have found spatial structures to be difficult to acquire for M2 learners (e.g., McKee and McKee, 1992; Ferrara and Nilsson, 2017; Shield and Meier, 2018; Boers-Visker, 2020; Gulamani et al., 2020). In contrast, M2 learners show higher usage of lexical signs


**FIGURE 2 |** Cross-linguistic similarities of the signs of *vet ekki* and *vet inte* [do not know]. STS image of VET-INTE from STS dictionary ID: 17937 (published with permission).

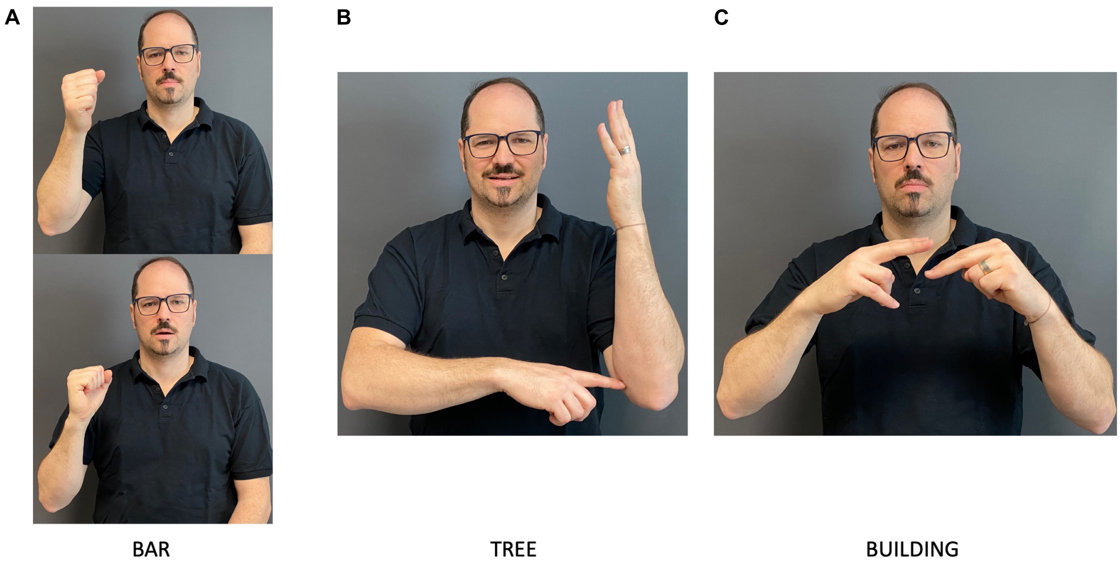


**FIGURE 3 |** Examples of lexical transfers. The signs are **(A)** BAR, **(B)** TREE and **(C)** BUILDING.

and fingerspelling. Furthermore, we found instances of cross-linguistic influence in the M1 group consisting of L1/Ln signs and variation in handshape configurations in lexical and depicting signs.

With respect to the above CLI observations in M1 and M2 signers, we can conclude that CLI is possible regardless of the modality difference, but it seems that the learners' modality experiences elicit different types of transfer. Even if the modalities are fundamentally different channels for perception and production, there are superficial and conceptual similarities. Same-modal language transfer allows for the direct physical transfer of the signs, i.e., as with the lexical transfer of L1/Ln signs into L2 STS, as well as the partly lexical transfer of mouthing. Different-modal transfers allow for more superficial and structural transfers that influence STS production. The perceived cross-linguistic similarities between Swedish words and lexical signs and the use of fingerspelling in STS obviously create motivation or possibility for the M2 learners to use lexical signs and fingerspelling, which contributes to the over-production of such signs.

On the contrary, the shared modality of sign languages contributes a more modality-based transfer in M1 signers through higher use of depiction in M1 signers compared with M2 signers. The M1 narratives from the short film clip "The Plank" consisted, to a large extent, of depicting signs that are contextually bounded and spontaneously created at the moment they are expressed. The M1 participants' production of such depicting signs can be seen as a positive transfer from the sign modality, i.e., the participants know how depicting signs are used in narratives and used these to a higher degree than lexical signs. Such a strategy works very well in this type of narrative; lexical signs are not required when retelling the actions in the clip, and thus, the production can be perceived as STS and "sign language" in general. However, we also found that the improvisation and use of many different depicting signs also meant that the participants used a range of different lexical signs (from both STS and other sign languages) for the same referent, particularly regarding the "beer glass."

Our findings link to previous CLI findings for spoken languages. First, the differences between M1 and M2 signers in the distribution of sign types could be linked to the assumption about the learners' perceived similarity of the source and recipient language. However, the perception of the similarities is configured differently between M1 and M2 learners. As M1 learners can resort to modality experience of at least one sign language, it allows for a positive transfer of modality-specific structures, such as the use of depicting signs. At the same time, M1 learners underuse fingerspelling, as this kind of knowledge is probably associated with knowledge of Swedish, i.e., it requires a level of multilingual competence. M2 learners, in contrast, do not have any experience of the sign modality (except some possible gestural knowledge) but resort to the L1 knowledge of Swedish. Thus, their sign distribution demonstrates an overproduction of lexical signs and fingerspelling as a result of the perceived similarity between spoken Swedish words and lexical signs and fingerspelling.

Furthermore, transfers based on sign modality were observed in M1 learners through lexical transfers, mouthing transfers, and handshape transfers. Interestingly, the qualitative analysis shows that it could be linked to forward and lateral transfers. Knowledge of international sign and/or ASL (as lingua franca) among some M1 participants also contributed to the lateral transfer of a few signs and mouthing transfers. However, interferences based on a forward transfer were hard to find. However, we observed some handshape transfers that could be a type of forward transfer (e.g., the Russian handshape for "window") and lexical transfer (e.g., transfer of Lithuanian sign of TREE).

Regarding the quantitative results, M1 learners use, as mentioned above, depicting signs to a greater extent than M2 learners and in a manner comparable to the baseline L1 signers (as the difference between M1 and L1 was not statistically significant). We believe this is an instance of CLI here as well. The M1 learners are still in the process of learning the lexical signs. In the meanwhile, the higher use of depicting signs may cover the M1 learners' limited knowledge of lexical signs. Since they have access to previous knowledge of how to use depicting signs, this is positively transferred to the L2 STS. In contrast, M2 learners have limited previous knowledge of using depicting signs. Instead, they rely on the "one word–one sign" learning strategy as it has an observed similarity that STS and Swedish share. Thus, both M1 and M2 learners rely on perceived similarities of STS to their L1 but in different ways. However, it should be noted that we have not considered any form of accuracy analysis in this study. Instead, we have focused on the performance of the sign categories only through use and distribution.

An analysis of qualitative aspects of negative transfer in the M2 group was harder to conduct. For instance, in our initial analysis, we noticed using fingerspelling and the use of lexical signs that are prepositions. Nevertheless, it was not entirely straightforward to mark them as non-target forms, i.e., as negative transfers, as such usage of fingerspelling and prepositions is apparent in the L1 group and part of the language contact between STS and STS Swedish. Instead, as mentioned, we have departed from the frequency and distribution to illustrate the M2 groups' usage of sign categories from the lens of CLI. However, future studies focusing on syntactic production may reveal interesting results regarding the use of prepositions in the M2 group, for example. The negative transfers in M1 were more apparent as they were, in fact, non-target forms.

In our study, the number of gestures was low among all three groups. The M2 group used the largest amount, but these only consisted of 3.0% of the total number of signs. L1 used the lowest number of gestures, only 1.6%, and the M1 group 2.6%. However, although not statistically significant, the slight difference between M2 and L1 signers *may* indicate that M2 signers transfer some of their gestural knowledge when producing narratives. Nor could any difference be found among the three groups in the sign category pointings. These results may be somewhat surprising for gestures and pointings because they are common strategies in both sign languages and as co-speech gestures. It may be caused by the movie clip "The Plank" being only 1 min long, and the content does not elicit gestures and pointings but rather lexical signs and depicting signs. If the groups had produced a longer narrative or their own stories, the gestures and pointings might have been more frequent. Future studies may reveal if this is the case and, if so, if there are group differences.

This study has focused on a particular group of M1 learners to be able to compare with M2 learners as equally as possible. Consequently, we focused on M1 learners with a comparable L1 background and educational background as the M2 learners. Still, there is a good amount of variability within the M1 group in terms of their L1 SLs and age. Furthermore, it was challenging to recruit enough participants to provide a good picture of the M1 acquisition. In our project Mulder, studying deaf migrants, there are a considerable number of participants not included here, with diverse linguistic and educational backgrounds that would not fit within the frame of this study.

It should be worth highlighting some individual (and group) variations associated with our M1 and M2 participants. First, regarding the learning time of L2 STS, it could be noted that some of the M1 learners have a shorter time of their learning of STS compared with the M2 learners. In addition, M1 learners are learning (written) Swedish simultaneously, while M2 learners are native speakers of Swedish. This fact can explain why the usage of fingerspelling is lower in the M1 group compared to the M2 (and L1) group. This also supports that lexical transfers of other sign languages are apparent in the M1 group and that the M2 group has an overproduction of mouthing, as previously reported (Mesch and Schönström, 2021). However, exposure time to STS (and other sign languages) may be much larger for the M1 participants compared with the M2 participants. Second, education level and social status may matter. All M2 learners are, in fact, students at the university level and hearing, i.e., they have a more privileged position in the Swedish society compared with the M1 learners. But it is not clear how this would affect their signing. Most M1 students also have some kind of education after the elementary level but no university level education. However, M1 learners benefit from cultural-bound access to the deaf community, as most participants seem to be building connections to the Swedish Deaf community. It is a larger step for a hearing M2 learner to get involved in this community, if possible. Furthermore, as earlier SLA research indicates, motivation matters and cultural-related motivation boosts learning a new language. Third, the cultural boundness and knowledge about international meetings between deaf people can also influence the M1 learners' signing. It can be found in terms of their higher use of depicting signs and the qualitative lexical and mouthing transfers we have accounted for in the result section, even if unconscious, at least with regard to handshape transfer. Finally, even though it is exceptionally hard to collect enough data from a group of sign language learners with a fully comparable background, especially for the M1 group, it is important to consider these individual and group variations in our results. This is also something future studies should consider.

To conclude, this study has shown that M2 learners exhibit cross-modal cross-linguistic transfer from Swedish (through higher usage of lexical signs and fingerspelling) and that M1 learners exhibit same-modal cross-linguistic transfer from L1/Ln sign languages through higher usage of depicting signs and use of signs from L1/Ln sign language and international signs. Furthermore, the study suggests that the modality-specific lexicon is harder for M2 learners to acquire despite possible underlying gestural knowledge. In contrast, M1 learners have access to modality-specific knowledge, overlapping access to gestural knowledge, and iconicity, which facilitates the modality-specific use of the lexicon and is open for direct lexical transfer from other sign languages. Thus, second language learning seems to be based on multimodality and multimodal competence, as well as multilingual competence. However, this study has only focused on the production of the lexicon. For future studies, it would be interesting to broaden the scope of possible CLI on other structures, especially from a morphosyntactic perspective, to see whether different grammatical profiles of spoken and sign languages influence the learning of the languages.

## DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Swedish Ethical Review Authority (DNR 2020-02865 and 2013/5:8). The patients/participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any identifiable images or data included in this article.

## AUTHOR CONTRIBUTIONS

KS designed the study and responsible for the analysis work. KS and IH collected the data and involved in manuscript drafting and revisions. Both authors contributed to the article and approved the submitted version.

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## REFERENCES

Battison, R. (1978). *Lexical Borrowing in American Sign Language*. Silver Spring, MD: Linstok Press.

Baus, C., Carreiras, M., and Emmorey, K. (2012). When does iconicity in sign language matter? *Lang. Cogn. Processes* 28, 261–271. doi: 10.1016/j.cognition.2008.05.012

Bochner, J. H., Christie, K., Hauser, P. C., and Searls, J. M. (2011). When is a difference really different? Learners' discrimination of linguistic contrasts in American Sign Language. *Lang. Learn.* 61, 1302–1327. doi: 10.1111/j.1467-9922.2011.00671.x

Boers-Visker, E. (2020). *Learning to Use Space: A Study Into the SL2 Acquisition Process of Adult Learners of Sign Language of the Netherlands*. Doctoral thesis. Amsterdam: LOT Publications.

Brentari, D., and Padden, C. A. (2001). "Native and foreign vocabulary in American Sign Language: a lexicon with multiple origins," in *Foreign Vocabulary in Sign Languages: A Cross-Linguistic Investigation of Word Formation*, ed. D. Brentari (Mahwah, NJ: Lawrence Erlbaum Associates), 87–119.

Casey, S., and Emmorey, K. (2009). Co-speech gesture in bimodal bilinguals. *Lang. Cogn. Processes* 24, 290–312. doi: 10.1080/01690960801916188

Chen Pichler, D. (2010). "Sources of handshape error in first-time signers of ASL," in *Deaf Around the World: The Impact of Language*, eds G. Mathur and D. J. Napoli (Oxford: Oxford University Press.), 96–126.

Chen-Pichler, D., and Koulidobrova, H. (2015). "Acquisition of sign language as a second language," in *The Oxford Handbook of Deaf Studies in Language (Oxford Library of Psychology)*, eds M. Marschark and P. E. Spencer (Oxford: Oxford University Press), 218–230. doi: 10.1093/oxfordhb/9780190241414.001.0001

Cormier, K., Quinto-Pozos, D., Sevcikova, Z., and Schembri, A. (2012). Lexicalization and de-lexicalization processes in sign languages: comparing depicting constructions and viewpoint gestures. *Lang. Commun.* 32, 329–348. doi: 10.1016/j.langcom.2012.09.004

Cormier, K., Schembri, A., and Woll, B. (2013). Pronouns and pointing in sign languages. *Lingua* 137, 230–247.

Crasborn, O. A., van der Kooij, E., Waters, D., Woll, B., and Mesch, J. (2008). Frequency distribution and spreading behavior of different types of mouth actions in three sign languages. *Sign Lang. Linguist.* 11, 45–67. doi: 10.1075/sll.11.1.04cra

Ferrara, L., and Nilsson, A.-L. (2017). Describing spatial layouts as an L2M2 signed language learner. *Sign Lang. Linguist.* 20, 1–26. doi: 10.1075/sll.20.1.01fer

Gulamani, S., Marshall, C., and Morgan, G. (2020). The challenges of viewpoint-taking when learning a sign language: data from the 'frog story' in British Sign Language. *Second Lang. Res.* 38, 55–87. doi: 10.1177/0267658320906855

Hodge, G., and Johnston, T. (2014). Points, depictions, gestures and enactment: partly lexical and non-lexical sign as core elements of single clause-like units in Auslan (Australian Sign Language). *Aust. J. Linguist.* 34, 262–291. doi: 10.1080/07268602.2014.887408

Holmström, I. (2019). Teaching a language in another modality: a case study from Swedish Sign Language L2 instruction. *J. Lang. Teach. Res.* 10, 659–672. doi: 10.17507/jltr.1004.01

Holmström, I. (2021). Modality-focused L2-instruction in Swedish sign language. *J. Linguist. Lang. Teach.* 12, 93–114.

Jarvis, S., and Pavlenko, A. (2008). *Cross-Linguistic Influence in Language and Cognition*. New York, NY: Taylor & Francis.

Johnston, T. A. (2012). Lexical frequency in sign languages. *J. Deaf Stud. Deaf Educ.* 17, 163–193. doi: 10.1093/deafed/enr036

Johnston, T. A., and Schembri, A. (2010). Variation, lexicalization and grammaticalization in signed languages. *Lang. Soc.* 131, 19–35. doi: 10.3917/ls.131.0019

Johnston, T., and Ferrara, L. (2012). "Lexicalization in signed languages: when is an idiom not an idiom?," in *Proceedings of the Selected Papers from the 3rd UK Cognitive Linguistics Conference*, Vol. 1 (London: United Kingdom Cognitive Linguistics Association), 229–248.

Kaufman, A. S., and Kaufman, N. L. (2004). *Kaufman Brief Intelligence Test*, Second Edn. Bloomington, MN: Pearson, Inc.

Koulidobrova, E. (2019). "Argument omission in SignL2 acquisition by deaf learners," in *Three Streams of Generative Language Acquisition Research: Selected papers from the 7th Meeting of Generative Approaches to Language Acquisition*. Language Acquisition and Language Disorders, Vol. 63, eds T. Ionin and M. Rispoli (Amsterdam: John Benjamins Publishing Company), 297–318.

Lepic, R. (2019). A usage-based alternative to "lexicalization" in sign language linguistics. *Glossa J. Gen. Linguist.* 4, 23. doi: 10.5334/gjgl.840

Liddell, S. K. (2003). *Grammar, Gesture, and Meaning in American Sign Language*. Cambridge: Cambridge University Press.

Marshall, C. R., and Morgan, G. (2015). From gesture to sign language: conventionalization of classifier constructions by adult hearing learners of British Sign Language. *Top. Cogn. Sci.* 7, 61–80. doi: 10.1111/tops.12118

Marshall, C., Bel, A., Gulamani, S., and Morgan, G. (2021). How are signed languages learned as second languages? *Lang. Linguist. Compass* 15:e12403. doi: 10.1111/lnc3.12403

McKee, R. L., and McKee, D. (1992). What's so hard about learning ASL?: students' & teachers' perceptions. *Sign Lang. Stud.* 75, 129–157.

Meier, R. P. (2002). "Why different, why the same? Explaining effects and non-effects of modality upon linguistic structure in sign and speech," in *Modality and Structure in Signed and Spoken Languages*, eds R. P. Meier and K. Cormier (New York, NY: Cambridge University Press), 1–2.

Mesch, J., and Schönström, K. (2018). "From design and collection to annotation of a learner corpus of sign language," in *Proceedings of the 8th Workshop on the Representation and Processing of Sign Languages: Involving the Language Community [Language Resources and Evaluation Conference (LREC)]*, eds M. Bono, E. Efthimiou, S.-E. Fotinea, T. Hanke, J. Hochgesang, J. Kristoffersen, et al. (Paris: European Language Resources Association (ELRA)), 121–126.

Mesch, J., and Schönström, K. (2021). Use and acquisition of mouth actions in L2 sign language learners: a corpus-based approach. *Sign Lang. Linguist.* 24, 36–62.

Mesch, J., Schönström, K., and Embacher, S. (2021). Mouthings in Swedish sign language: an exploratory study. *Grazer Linguist. Stud.* 93, 107–135.

Odlin, T. (1989). *Language Transfer. Cross-Linguistic Influence in Language Learning*. Cambridge: Cambridge University Press.

Ortega, G. (2017). Iconicity and sign lexical acquisition: a review. *Front. Psychol.* 8:1280. doi: 10.3389/fpsyg.2017.01280

Ortega, G., and Morgan, G. (2015a). Phonological development in hearing learners of a sign language: the influence of phonological parameters, sign complexity, and iconicity. *Lang. Learn.* 65, 660–688. doi: 10.1111/lang.12123

Ortega, G., and Morgan, G. (2015b). The effect of iconicity in the mental lexicon of hearing non-signers and proficient signers: evidence of cross-modal priming. *Lang. Cogn. Neurosci.* 30, 574–585. doi: 10.1080/23273798.2014.959533

Ortega, G., Schiefner, A., and Özyürek, A. (2019). Hearing non-signers use their gestures to predict iconic form-meaning mappings at first exposure to signs. *Cognition* 191:103996. doi: 10.1016/j.cognition.2019.06.008

Özyürek, A. (2012). "Gesture," in *Sign Language: An International Handbook*, eds R. Pfau, M. Steinbach, and B. Woll (Berlin: De Gruyter Mouton), 626–646. doi: 10.1515/9783110261325.626

Perniss, P. (2012). "Use of sign space," in *Sign Language. An International Handbook*, eds R. Pfau, M. Steinbach, and B. Woll (Berlin: De Gruyter), 412–431.

Ringbom, H. (2007). *The Importance of Cross-Linguistic Similarity in Foreign Language Learning: Comprehension, Learning and Production*. Clevedon: Multilingual Matters.

Rosen, R. S. (2004). Beginning L2 production errors in ASL lexical phonology: a cognitive phonology model. *Sign Lang. Linguist.* 7, 31–61. doi: 10.1075/sll.7.1.04beg

Schembri, A. (2003). "Rethinking "classifiers" in signed languages," in *Perspectives on Classifier Constructions in Sign Languages*, ed. K. Emmorey (Mahwah, NJ: Lawrence Erlbaum), 3–34.

Schönström, K. (2021). Sign languages and second language acquisition research: an introduction. *J. Eur. Second Lang. Assoc.* 5, 30–43. doi: 10.22599/jesla.73

Schönström, K., and Mesch, J. (2017). *Dataset. The Project From Speech to Sign – Learning Swedish Sign Language as a Second Language*. Stockholm: Department of Linguistics, Stockholm University.

Schönström, K., and Mesch, J. (2019). "Frequency and distribution of signs and sign proficiency in second language (L2) signers – a longitudinal and comparative study," in *Paper Presented at the TISLR13, the 13th conference of Theoretical Issues in Sign Language Research 26-28 September, 2019*, Hamburg.

Shield, A., and Meier, R. P. (2018). Learning an embodied visual language: four imitation strategies available to sign learners. *Front. Psychol.* 9:811. doi: 10.3389/fpsyg.2018.00811

Taub, S., Galvan, D., Piñar, P., and Mather, S. (2008). "Gesture and ASL L2 acquisition," in *Sign Languages: Spinning and Unravelling the Past, Present and Future. TISLR9, Forty Five Papers and Three Posters From the 9th Theoretical Issues in Sign Language Research Conference, Florianopolis, Brazil, December 2006*, ed. R. M. de Quadros (Petrópolis: EditoraArara Azul), 639–651.

Wallin, L. (1996). *Polysynthetic Signs in Swedish Sign Language*. Doctoral thesis. Stockholm: Department of Linguistics, Stockholm University.

Wallin, L., and Mesch, J. (2018). *Annoteringskonventioner för Teckenspråkstexter. Version 7, January 2018. [Annotation Guidelines for Sign Language Texts]*. Stockholm: Department of Linguistics, Stockholm University.

Woll, B. (2013). "Second language acquisition of sign language," in *The Encyclopedia of Applied Linguistics*, ed. C. A. Chapelle (Oxford: Wiley-Blackwell). doi: 10.1002/9781405198431.wbeal1050

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# I See What You Are Saying: Hearing Infants' Visual Attention and Social Engagement in Response to Spoken and Sign Language

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Infants are endowed with a proclivity to acquire language, whether it is presented in the auditory or visual modality. Moreover, in the first months of life, listening to language supports fundamental cognitive capacities, including infants' facility to form object categories (e.g., dogs and bottles). Recently, we have found that for English-acquiring infants as young as 4 months of age, this precocious interface between language and cognition is sufficiently broad to include not only their native spoken language (English), but also sign language (American Sign Language, ASL). In the current study, we take this work one step further, asking how "sign-naïve" infants—hearing infants with no prior exposure to sign language—deploy their attentional and social strategies in the context of episodes involving either spoken or sign language. We adopted a now-standard categorization task, presenting 4- to 6-month-old infants with a series of exemplars from a single category (e.g., dinosaurs). Each exemplar was introduced by a woman who appeared on the screen together with the object. What varied across conditions was whether this woman introduced the exemplar by speaking (English) or signing (ASL). We coded infants' visual attentional strategies and their spontaneous vocalizations during this task. Infants' division of attention and visual switches between the woman and exemplar varied as a function of language modality. In contrast, infants' spontaneous vocalizations revealed similar patterns across languages. These results, which advance our understanding of how infants allocate attentional resources and engage with communicative partners across distinct modalities, have implications for specifying our theories of language acquisition.

**Keywords: spoken language, sign language, infants, categorization, multimodal**

## INTRODUCTION

Infants are endowed with a proclivity to acquire language (Kuhl, 2000). Importantly, this propensity is not restricted to a single modality: infants are prepared to acquire any human language, whether it is spoken or signed (Meier and Newport, 1990; Bavelier et al., 2003; Petitto et al., 2004; Pichler, 2011; Newport and Meier, 2017). Even without exposure to sign language, infants prefer looking at sign language over non-linguistic hand movements (Krentz and Corina, 2008) and are sensitive to its linguistic features (Baker et al., 2006; Palmer et al., 2012; Stone et al., 2018). However, for infants who are only exposed to spoken language, early sensitivity to sign language wanes over the first year of life (Baker et al., 2006; Krentz and Corina, 2008; Palmer et al., 2012; Stone et al., 2018). Infants' natural tendency to acquire language is thus flexible with respect to modality but is rapidly attuned to the language modality of the linguistic communit(ies) that surround them.

Infants' preference for language also has powerful downstream consequences. For hearing infants as young as 4 months of age, listening to infant-directed speech modulates neural activity in such a way as to engage early attentional components (Woodruff Carr et al., 2021). In addition, listening to language supports infants' fundamental cognitive capacity to form object categories (Waxman and Markow, 1995; Balaban and Waxman, 1997; Waxman and Braun, 2005; Ferry et al., 2010). Evidence for this early emerging interface between language and cognition comes from a robust paradigm, in which infants are familiarized to a series of exemplars, all from the same category (e.g., dinosaurs). What varies is whether these exemplars are introduced in conjunction with infant-directed speech (e.g., "look at the modi") or with well-matched non-linguistic sounds (e.g., sine-wave tones, backward speech). At test, infants then view two new exemplars: one from the now-familiar category (e.g., a new dinosaur) and another from a novel category (e.g., a fish). If infants form the object category during familiarization, they should distinguish the novel from the familiar category objects at test. The results reveal that for infants from 3 to 12 months, listening to language confers a cognitive advantage: Infants who hear infant-directed speech in conjunction with familiarization exemplars successfully form object categories, whereas infants who see the same exemplars paired with non-linguistic acoustic signals do not (Waxman and Markow, 1995; Balaban and Waxman, 1997; Waxman and Braun, 2005; Fulkerson and Waxman, 2007; Ferry et al., 2010, 2013). This early link between language and cognition provides a foundation for learning and becomes increasingly precise with development (Perszyk and Waxman, 2018).

In recent work we asked whether this precocious link is sufficiently abstract to include language presented in the visual modality (Novack et al., 2021). Focusing on 4- to 6-month-old hearing infants with no prior exposure to sign language, we adapted the categorization task described above, this time pairing each familiarization object with a woman who communicated about the object in one of two ways. In a non-linguistic condition, she pointed at the object, and looked back and forth between the object and the infant, providing social-communicative pedagogical cues but no linguistic information. In a sign language condition, she signed the phrase "LOOK MODI, YOU SEE MODI?" in American Sign Language (ASL), together with the same pointing and eye-gaze cues presented in the non-linguistic condition.

The results were straightforward: At 4 months, infants in the sign language condition—but not the non-linguistic condition—successfully formed object categories (Novack et al., 2021). By 6 months, this advantage had waned: infants failed to form object categories in either condition. This developmental tuning is consistent with evidence that between 4 and 6 months, infants rapidly narrow the range of signals that they will link to cognition, a narrowing that is shaped by the language(s) in which they are immersed (e.g., Ferry et al., 2013; Perszyk and Waxman, 2018, 2019).

One key feature of the design used in Novack et al. (2021), which we retain in the current study, is worth noting: this was the first study of its kind in which the communicative partner was visible, engaging the infant from the screen. This is an important departure from prior instantiations of the object categorization task in which objects were presented visually, and the linguistic and non-linguistic information was presented acoustically (e.g., Waxman and Markow, 1995; Balaban and Waxman, 1997; Waxman and Braun, 2005; Fulkerson and Waxman, 2007; Ferry et al., 2010, 2013). Necessary to study infants' responses to sign language, this design shift also provides the unique opportunity to examine the broader matter of how infants integrate multiple sources of information (the images of objects and the language input to describe them) when presented within a single modality.

Here, we advance the prior design to focus on infants' visual attentional and social engagement strategies in the context of observing either sign language or spoken language. Moving beyond object categorization as an outcome measure, we focus instead on infants' engagement during learning, as they view a series of objects, each accompanied by a woman who introduces each object in either ASL or in spoken English. At issue is whether infants (i) deploy different visual attentional strategies, and/or (ii) adopt different social engagement strategies, in the context of either spoken versus sign language.

Indeed, there are good reasons to expect that infants' engagement may differ when presented with sign language or spoken language. Consider, for example, the case of object labeling. Infants acquiring spoken language can devote their full visual attention to the object under description, as they receive the linguistic information through the auditory channel. In contrast, infants acquiring sign language must divide their visual attention strategically between the object and a signer.

In designing our measures, we took advantage of compelling evidence that young children who are exposed to sign language do indeed divide their visual attention strategically and fluidly between a signer and a referent object during word-learning episodes. For instance, sign-exposed toddlers assess the structure of linguistic input to advantageously allocate their visual attention between a signer and a referent when fast-mapping novel signs (Lieberman et al., 2021) or when finding a known referent (MacDonald et al., 2020). They also produce frequent gaze shifts between visual referents and communicative partners during interaction, and do so in ways that differ from their speech-exposed peers (Lieberman et al., 2014). Clearly, children exposed to sign language adapt their attentional resources to support learning language in the visual modality. But what is the starting point? What visual attentional strategies do very young infants bring to the task of acquisition, and how are these then adapted to accommodate language acquisition in each modality?

In designing our measures, we also took advantage of evidence documenting that hearing infants' vocalizations serve as an index of their social engagement. Infants start to vocalize within their first few weeks, producing reflexive sounds such as coughing, sneezing, and crying. Infants then progressively extend their vocal repertoires, adding cooing and laughing (1–4 months) followed by babbling (5–10 months; Oller, 1978; Nathani et al., 2006). Hearing infants are sensitive to how their caregivers respond to babbling; when caregivers respond contingently to their babbling, infants adapt their own vocalizations to match the structure of their caregiver's utterances (Goldstein et al., 2003; Goldstein and Schwade, 2008).

Young hearing infants are also attuned to how their own vocalizations serve as a means of engaging others. For example, infants' reactions during the still-face paradigm document that they systematically increase their own vocalizations in an attempt to re-engage a communicative partner who stops interacting with them (Delgado et al., 2002; Goldstein et al., 2009). Hence, infant vocalizations can be a powerful indicator of their engagement with a social partner within an interactive turn-taking communicative context. At issue is whether "sign-naïve" infants appreciate the communicative potential of sign language, producing vocalizations to engage a communicative partner who signs, just as they engage a communicative partner who speaks.

In the current study, we ask how 4- to 6-month-old sign-naive infants deploy their visual attention and vocal responses as they view a series of images, along with a woman who indicates each image either in English or in ASL. This design, which builds upon (Novack et al., 2021), permits us to compare how infants divide their visual attention between a communicative partner and an object, across modalities. It also permits us to assess how infants use their own vocalizations to respond to social partners communicating in different modalities. Finally, we examine infants' vocalizations in two distinct phases: an active phase (when the woman is actively engaged, labeling objects, looking back and forth between the objects and the infant) versus a still phase (when she pauses all activity, casting her glance downward).[1] Comparing infants' vocalizations across these phases permits us to ask whether infants are sensitive to the turn-taking episodes of communicative behavior. Based on prior work, we expect that infants in the spoken language condition will vocalize more in the still phase than the active phase (Delgado et al., 2002; Goldstein et al., 2009). It is an open question as to how infants will respond in the sign language condition. If sign-naïve infants appreciate the communicative potential of sign language, they too should vocalize more in the still phase than the active phase. However, it is also possible that sign-naïve infants do not recognize the communicative potential of sign language; if this is the case, they should not vocalize more in the still phase.

[1]Note, the current study methods differ somewhat from the prior published work (Novack et al., 2021), which used slightly different stimuli. Novack et al. (2021) compared sign language to non-linguistic pointing, here we compare sign language to spoken language. Additionally, stimuli in the version used by Novack et al. (2021) had the woman fade out of view between communicative episodes. Here, the woman remains on screen the entire time.

# MATERIALS AND METHODS

## Participants

Participants included 45 infants between the ages of 4 and 6 months (range = 4.05–6.97). There were 23 infants (12 females, $M_{age}$ = 5.48, $SD_{age}$ = 0.86) in the sign language condition and 22 infants (13 females, $M_{age}$ = 5.37, $SD_{age}$ = 1.00) in the spoken language condition. Infants were recruited from primarily college-educated, white families from the greater Chicago area. All infants were full term, had normal hearing, and were exposed primarily to spoken English at home. The study was approved by the IRB at Northwestern University under the protocol STU00104124.

## Stimuli

Infants viewed a video in which a woman introduced a series of eight exemplars belonging to a single object category. In each trial, a single image (a colored line drawling of either a fish or a dinosaur) appeared on the bottom right or left of the screen; the woman appeared in the top center of the screen. The woman was a hearing, bimodal-bilingual person natively fluent in both ASL and English. To introduce each object, she clapped her hands to attract infants' visual attention to the screen, then produced an *Active* phase and a *Still* phase (See **Figure 1**). This sequence was repeated twice for each object.

Active phase (approximately 4,500 ms): The woman looked at, pointed to, and labeled the object. In the spoken language condition, she said: "Look at the Modi. Do you see the Modi?," using infant-directed speech. In the sign language condition, she signed the phrase, "LOOK MODI, YOU SEE MODI?," using infant-directed ASL. The pseudo-sign used for MODI was a phototactically well-formed ASL noun (Supalla and Newport, 1978), consisting of two short, straight movements with contact at the cheek, and with a single "8"—handshape. In both conditions, she pointed to and looked at the object while labeling it.

Eye-gaze was identical across the two conditions. The woman looked directly at the infant as she clapped, and then turned to glance at the object as she pointed, saying "look at the Modi/LOOK MODI." She then turned her gaze back toward the infant, saying "do you see the Modi…/YOU SEE MODI…." As she completed this phrase, she glanced back to the object and pointed to it when she mentioned its name.

Still phase (approximately 3,700 ms). Next, the woman looked down, averting her eye-gaze from the infant and remaining still.

## Procedure

Infants were tested in a quiet room in a university laboratory. Infants sat on their caregiver's lap approximately 1 meter from a large (115 cm high x 154 cm wide) screen. A hidden video-camera recorded infants' eye movements and vocalizations. Caregivers wore opaque glasses and were instructed not to interact with their infants during the experiment. Infants saw eight trials in which a woman labeled each object, all from

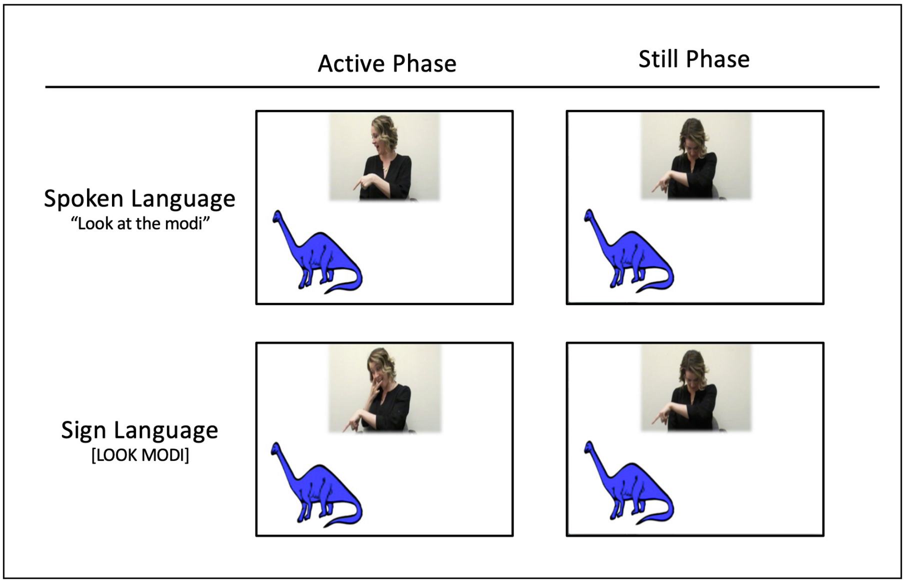


**FIGURE 1 |** Screenshots depicting one representative trial of the eight trials. In the active phase (left), the woman looks back and forth between the infant and the object while pointing to it and labeling it. This is followed by a still phase (right) in which she ceases all activity, gazing down to break eye-contact. Infants were randomly assigned to condition; in each condition, we counterbalanced (i) whether infants saw a series of images of fish or dinosaurs, and (ii) whether the first image appeared on the right or left side (the image appeared on alternating sides across the eight trials).

the same category, either in spoken English or ASL. The images (either fish or dinosaur) infants viewed and the side of the first image (right/left) were counterbalanced across participants.

## Behavioral Coding

### Visual Attention Coding

Trained coders identified infant gaze during each trial, assessing whether the infant was looking on or off screen, and whether the infant was looking toward the woman or the object. Inter-rater reliability, calculated for 1/3 of the participants, was high for both the proportion of on-screen looking (Pearson's $r = 0.85$, $p < 0.001$) as well as proportion of looking to the woman versus object ($r = 0.90$, $p < 0.001$).

### Vocalization Coding

Vocalization coding, conducted by an independent set of trained coders, identified any infant vocalizations produced in each trial. Vocalizations that occurred within 1,000 ms of each other were coded as a single unit. For each vocalization, coders recorded whether it was produced in the *active* or *still* phase. Videos from two infants in the spoken language condition could not be coded for vocalizations. Reliability was calculated for 1/3 of the participants. Agreement on whether there was a vocalization in each video phase averaged 97% across all trials.

# RESULTS

## Visual Attention

Infants in both conditions were highly attentive and engaged throughout the task. Those in the sign language condition looked for 80% (SD = 10%) of the total time, whereas infants in the spoken language condition allocated even more attention, looking for 92% (SD = 5%) of the total presentation, $t(44) = 5.083$, $p < 0.001$.

To assess patterns and division of visual attention, we calculated infants' preference for the woman by dividing their total looking to the woman by their total combined looking to the woman or the object. We then ran a mixed ANOVA on infants' proportion of attention to the woman with condition (spoken and sign) as a between-subject's variable, phase (active and still) as a within-subject's variable, and age as a covariate. The analysis revealed main effects of both condition, ($F(1,42) = 12.42$, $p = 0.001$) and phase ($F(1,42) = 124.780$, $p < 0.001$), qualified by a condition by phase interaction $F(1,42) = 8.10$, $p = 0.007$. There was also a significant effect of age ($F(1,42) = 8.96$, $p = 0.005$), indicating that with age, infants devoted more attention to the woman.

The condition by age interaction is depicted in **Figure 2**. Infants in both conditions devoted more visual attention to the woman than the object; and more to the woman when she was actively communicating than when she was still. Interestingly, the relative difference in attention to the woman varied as a function of condition: infants in the spoken language condition were quite vigilant, focusing predominantly on the woman even in the still phase; infants in the sign language condition were more likely to disengage from the woman when she was still, an outcome that permitted them to devote more attention to the object.

To test the possibility that infants in the spoken language condition were indeed more vigilant to the woman, we tallied the number of times each infant shifted their visual attention between the woman and the object (following analyses in

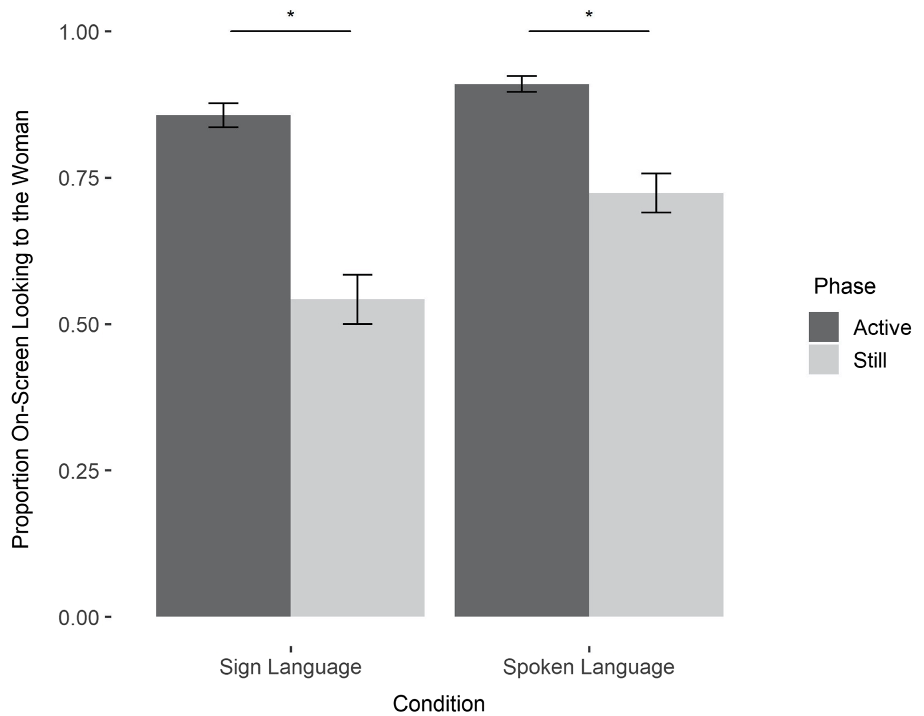


**FIGURE 2 |** Proportion of on-screen looking to the woman (as compared to the object) by condition and phase. Across both conditions, infants looked at the woman more during the active phase than the still phase (sign: $M_{active} = 85\%$ $SD_{active} = 10\%$, $M_{still} = 54\%$, $SD_{active} = 20\%$, $t(22) = 9.08$, $p < 0.001$; spoken: $M_{active} = 91\%$ $SD_{active} = 6\%$, $M_{still} = 72\%$, $SD_{active} = 16\%$, $t(21) = 6.53$, $p < 0.001$). This difference between active and still was greater for the sign language condition than the spoken language condition (interaction: $p < 0.001$).

Lieberman et al., 2014). We found that infants' tendency to switch their visual attention between the woman and the object (during any phase) varied as function of language modality: Infants in sign language condition switched significantly more times than did infants in the spoken language condition (sign: $M = 5.40$ switches, $SD = 1.38$, spoken: $M = 4.26$ switches, $SD = 1.84$, $t(1,43) = 2.359$, $p = 0.02$).

## Vocalizations

Most infants vocalized at least once ($N_{sign} = 19$, $N_{spoken} = 11$). On average, infants in the sign language condition produced 4.96 ($SD = 4.99$) vocalizations, and infants in the spoken language condition produced 2.85 ($SD = 4.51$), which was not different by condition, $t(41) = 1.5$, $p = 0.2$.

We tallied, for each infant, all instances of vocalizations that occurred in either the active or still phases. We submitted this to a generalized mixed effect model with phase (active and still) and condition (spoken and sign) as fixed effects, participant as a random effect, and age as a covariate. There was a significant main effect of phase; as expected, infants vocalized more during the still phase ($M = 3.42$, $SD = 3.94$) than the active phase ($M = 0.93$, $SD = 2.25$; $\beta = 1.28$, $SE = 0.22$, $\chi^2(2) = 65.1$, $p < 0.0001$). Indeed, vocalizations during the active phase were rare in both conditions (**Figure 3**, dark bars). There were no other significant main effects or interactions ($ps > 0.1$). Thus, 4- to 6-month-old hearing infants appear to be responsive to the communicative value of sign language, restricting their vocal responses to the breaks in communication, just as they do in response to spoken language.

## DISCUSSION

Human language not only engages infants from birth, but also affords powerful conceptual advantages. In the first few months of life, infants' engagement with language provides the foundation for establishing a link between language, both spoken and sign, and core cognitive capacities such as object categorization (Perszyk and Waxman, 2018; Novack et al., 2021). The goal of the current study was to advance the evidence by assessing how 4- to 6-month-old sign-naïve infants deploy their visual attention and social-communicative strategies in the context of episodes involving either spoken or sign language.

Our findings reveal both commonalities and differences in infants' responses to spoken and sign language. First, whether they were presented with spoken English or ASL, infants directed their visual attention predominantly to the woman during the active phase. Yet when the woman stopped communicating during the still phase, infants' performance between the two conditions differed: those in the spoken language condition were more likely to continue to gaze at the woman than were those in sign language condition. This difference during the still phase may reflect infants' language experience: we suspect that because they have had more exposure to spoken English

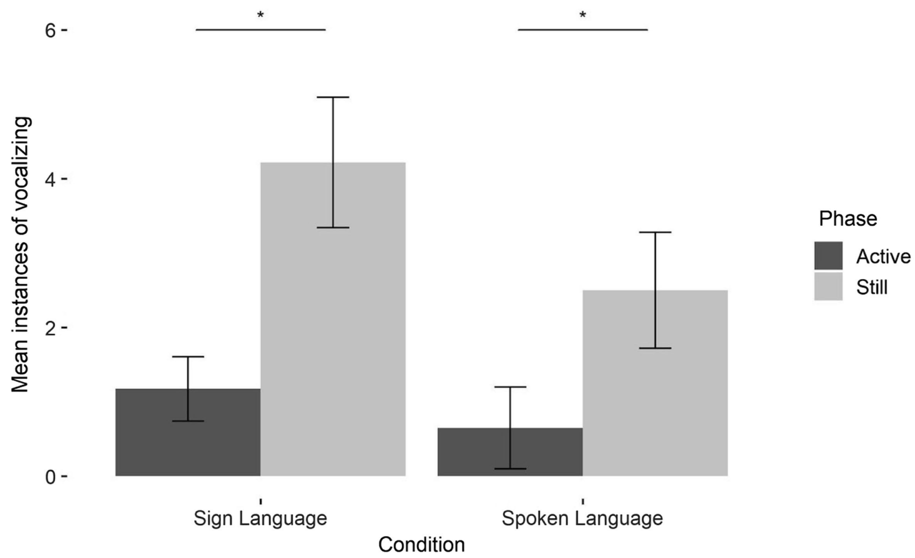


**FIGURE 3 |** Vocalization production by condition and phase. Within both conditions, more vocalizations occurred during the still phase than the active phase (sign: $M_{active} = 1.17$, $SD_{active} = 2.08$, $M_{still} = 4.22$, $SD_{still} = 4.21$, $t(22) = 3.5$, $p = 0.002$; spoken: $M_{active} = 0.7$, $SD_{active} = 2.45$, $M_{still} = 2.55$, $SD_{still} = 3.46$, $t(19) = 3.1$, $p = 0.005$).

than to ASL, hearing infants are more strongly motivated to attend vigilantly to a partner who communicates through speech. What remains unknown is whether infants' vigilance in the spoken condition reflects their greater exposure to English in particular, or to any language presented in the acoustic modality. In future work, it will be important to address this question.

Second, infants in both conditions produced more vocalizations when the woman was still than when she was actively communicating. This increase in vocalizations during the still phase is consistent with the possibility that infants were trying to re-engage the woman or bid her back. Together, these outcomes accord well with the hypothesis that 4- to 6-month-old hearing infants, never before exposed to sign, appreciate the communicative status of *both* spoken and sign language. It also aligns with evidence suggesting that young infants recognize the linguistic potential of language across modalities (Baker et al., 2006; Krentz and Corina, 2008; Palmer et al., 2012; Stone et al., 2018).

These findings also offer a new perspective for investigating infants' language acquisition across modalities. In particular, the visual presence of the woman producing language is far from trivial. Certainly, her presence on screen was required for the sign language condition. But we found that infants devoted considerable visual attention to the woman both in the sign language condition (when they *had* to look at her to glean language information), as well as in the spoken language condition (when they could have devoted their visual attention to the object). Infants' responses in the sign language condition offer insight into how they deploy their patterns of visual and social-engagement in a "looking-while-looking" task, in which the objects and linguistic information are both presented to the visual system. This provides an important counterpoint to the more standard 'looking-while-listening' tasks, in which objects are presented to the visual system and linguistic information is presented in an auditory stream (e.g., Ferry et al., 2010, 2013; Bergelson and Swingley, 2012; Fernald et al., 2013).

Our findings with sign-naïve infants contribute to recent research testing sign-exposed children in language learning tasks (MacDonald et al., 2020; Lieberman et al., 2021). The distinct attentional responses to language in different modalities, observed here in early infancy, must be independent of language exposure, but may still lay a foundation for the later strategies that emerge specifically for sign-exposed children. In future work it will be important to explore how these patterns emerge and change across development, and in response to different language environments.

It will also be important in future work to address some limitations in the current design. One limitation is that here, we have examined only a single spoken language (English) and a single sign language (ASL). At issue is how broadly these effects hold and how they are mediated by language familiarity and language modality. Another limitation is our reliance on infant vocalizations as an index of social engagement. Certainly this focus on infant vocalizations is well-motivated, but it will also be important to consider infant behavior more broadly, examining for example their motor behaviors as an index of their social engagement. For example, it will be fascinating to assess whether sign-naïve infants attempt to imitate components of the signer's hand movements. Third, it will be important to delve more deeply into infants' responses to the woman, comparing their responses documented here to their responses when interacting with a "live" woman. We presented video-recordings because our goal was to present the same woman (a native bi-modal bi-lingual speaker of English and ASL) to all infants. This decision was motivated by strong evidence that 4- to 6-month-old Western-raised infants respond to and understand social communicative interactions from video recordings (e.g., Senju and Csibra, 2008; Lewkowicz and Hansen-Tift, 2012; Liberman et al., 2021), as they did here. But in future work, it will be important to assess infants' behavior with communicators that are physically present.

Finally, to capture the early attentional and social capacities that infants bring to the language acquisition process, we focused on hearing infants with no prior exposure to sign language. However, it is also important to ask these questions with sign-exposed infants, as well as infants exposed to both sign and spoken language (bi-modal bilinguals). ASL-exposed infants have been shown to demonstrate enhanced gaze control and gaze following as a result of their early visual language experience (Brooks et al., 2020; Bosworth and Stone, 2021). Comparing their attentional patterns to those of sign-native infants will further elucidate the ways in which infants adjust their attentional processes on the basis of their exposure.

The current evidence, which sheds new light on how very young infants allocate their visual attention and engage with communicative partners across different modalities, advances our understanding of the tools infants bring with them to the language learning process and the flexibility with which they deploy them in responding to diverse language experiences.

## DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author.

## ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Northwestern University IRB. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin. Written informed consent was obtained from the individual(s) for the publication of any identifiable images or data included in this article.

## AUTHOR CONTRIBUTIONS

MN, DC, and SW contributed to the design and implementation of the research methods, coding, data analysis, and writing of the manuscript. All authors contributed to the article and approved the submitted version.

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## SUPPLEMENTARY MATERIAL

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## REFERENCES

Baker, S. A., Golinkoff, R. M., and Petitto, L.-A. (2006). New insights into old puzzles from infants' categorical discrimination of soundless phonetic units. *Lang. Learn. Dev.* 2, 147–162. doi: 10.1207/s15473341lld0203_1

Balaban, M. T., and Waxman, S. R. (1997). Do words facilitate object categorization in 9-month-old infants? *J. Exp. Child Psychol.* 64, 3–26. doi: 10.1006/jecp.1996.2332

Bavelier, D., Newport, E. L., and Supalla, T. (2003). "Signed or spoken: children need natural languages." in *Cerebrum: The Dana Forum on Brain Science*, 19–32.

Bergelson, E., and Swingley, D. (2012). At 6–9 months, human infants know the meanings of many common nouns. *Proc. Natl. Acad. Sci.* 109, 3253–3258. doi: 10.1073/pnas.1113380109

Bosworth, R. G., and Stone, A. (2021). Rapid development of perceptual gaze control in hearing native signing infants and children. *Dev. Sci.* 24:e13086. doi: 10.1111/desc.13086

Brooks, R., Singleton, J. L., and Meltzoff, A. N. (2020). Enhanced gaze-following behavior in deaf infants of deaf parents. *Dev. Sci.* 23:e12900. doi: 10.1111/desc.12900

Delgado, C. E., Messinger, D. S., and Yale, M. E. (2002). Infant responses to direction of parental gaze: A comparison of two still-face conditions. *Infant Behav. Dev.* 25, 311–318. doi: 10.1016/S0163-6383(02)00096-6

Fernald, A., Marchman, V. A., and Weisleder, A. (2013). SES differences in language processing skill and vocabulary are evident at 18 months. *Dev. Sci.* 16, 234–248. doi: 10.1111/desc.12019

Ferry, A. L., Hespos, S. J., and Waxman, S. R. (2010). Categorization in 3- and 4-month-old infants: an advantage of words over tones. *Child Dev.* 81, 472–479. doi: 10.1111/j.1467-8624.2009.01408.x

Ferry, A. L., Hespos, S. J., and Waxman, S. R. (2013). Nonhuman primate vocalizations support categorization in very young human infants. *Proc. Natl. Acad. Sci.* 110, 15231–15235. doi: 10.1073/pnas.1221166110

Fulkerson, A. L., and Waxman, S. R. (2007). Words (but not tones) facilitate object categorization: evidence from 6-and 12-month-olds. *Cognition* 105, 218–228. doi: 10.1016/j.cognition.2006.09.005

Goldstein, M. H., King, A. P., and West, M. J. (2003). Social interaction shapes babbling: testing parallels between birdsong and speech. *Proc. Natl. Acad. Sci.* 100, 8030–8035. doi: 10.1073/pnas.1332441100

Goldstein, M. H., and Schwade, J. A. (2008). Social feedback to infants' babbling facilitates rapid phonological learning. *Psychol. Sci.* 19, 515–523. doi: 10.1111/j.1467-9280.2008.02117.x

Goldstein, M. H., Schwade, J. A., and Bornstein, M. H. (2009). The value of vocalizing: five-month-old infants associate their own noncry vocalizations with responses from caregivers. *Child Dev.* 80, 636–644. doi: 10.1111/j.1467-8624.2009.01287.x

Krentz, U. C., and Corina, D. P. (2008). Preference for language in early infancy: the human language bias is not speech specific. *Dev. Sci.* 11, 1–9. doi: 10.1111/j.1467-7687.2007.00652.x

Kuhl, P. K. (2000). A new view of language acquisition. *Proc. Natl. Acad. Sci.* 97, 11850–11857. doi: 10.1073/pnas.97.22.11850

Lewkowicz, D. J., and Hansen-Tift, A. M. (2012). Infants deploy selective attention to the mouth of a talking face when learning speech. *Proc. Natl. Acad. Sci.* 109, 1431–1436. doi: 10.1073/pnas.1114783109

Liberman, Z., Kinzler, K. D., and Woodward, A. L. (2021). Origins of homophily: infants expect people with shared preferences to affiliate. *Cognition* 212:104695. doi: 10.1016/j.cognition.2021.104695

Lieberman, A. M., Fitch, A., and Borovsky, A. (2021). Flexible fast-mapping: deaf children dynamically allocate visual attention to learn novel words in American sign language. *Dev. Sci.* 25:13166. doi: 10.1111/desc.13166

Lieberman, A. M., Hatrak, M., and Mayberry, R. I. (2014). Learning to look for language: development of joint attention in young deaf children. *Lang. Learn. Dev.* 10, 19–35. doi: 10.1080/15475441.2012.760381

MacDonald, K., Marchman, V. A., Fernald, A., and Frank, M. C. (2020). Children flexibly seek visual information to support signed and spoken language comprehension. *J. Exp. Psychol. Gen.* 149, 1078–1096. doi: 10.1037/xge0000702

Meier, R. P., and Newport, E. L. (1990). Out of the hands of babes: On a possible sign advantage in language acquisition. *Language* 66, 1–23. doi: 10.1353/lan.1990.0007

Nathani, S., Ertmer, D. J., and Stark, R. E. (2006). Assessing vocal development in infants and toddlers. *Clin. Linguist. Phon.* 20, 351–369. doi: 10.1080/02699200500211451

Newport, E. L., and Meier, R. P. (2017). "The acquisition of American sign language," in *The Crosslinguistic Study of Language Acquisition*. ed. D. I. Slobin (United Kingdom: Psychology Press), 881–938.

Novack, M. A., Brentari, D., Goldin-Meadow, S., and Waxman, S. (2021). Sign language, like spoken language, promotes object categorization in young hearing infants. *Cognition* 215:104845. doi: 10.1016/j.cognition.2021.104845

Oller, D. K. (1978). Infant vocalization and the development of speech. *Allied Health Behav. Sci.* 1, 523–549.

Palmer, S. B., Fais, L., Golinkoff, R. M., and Werker, J. F. (2012). Perceptual narrowing of linguistic sign occurs in the 1st year of life. *Child Dev.* 83, 543–553. doi: 10.1111/j.1467-8624.2011.01715.x

Perszyk, D. R., and Waxman, S. R. (2018). Linking language and cognition in infancy. *Annu. Rev. Psychol.* 69, 231–250. doi: 10.1146/annurev-psych-122216-011701

Perszyk, D. R., and Waxman, S. R. (2019). Infants' advances in speech perception shape their earliest links between language and cognition. *Sci. Rep.* 9, 1–6. doi: 10.1038/s41598-019-39511-9

Petitto, L. A., Holowka, S., Sergio, L. E., Levy, B., and Ostry, D. J. (2004). Baby hands that move to the rhythm of language: hearing babies acquiring sign languages babble silently on the hands. *Cognition* 93, 43–73. doi: 10.1016/j.cognition.2003.10.007

Pichler, D. C. (2011). "Using Early ASL word order to shed light on word order Variability in sign Language," in *Variation in the Input* (Berlin: Springer), 157–177.

Senju, A., and Csibra, G. (2008). Gaze following in human infants depends on communicative signals. *Curr. Biol.* 18, 668–671. doi: 10.1016/j.cub.2008.03.059

Stone, A., Petitto, L.-A., and Bosworth, R. (2018). Visual sonority modulates infants' attraction to sign language. *Lang. Learn. Dev.* 14, 130–148. doi: 10.1080/15475441.2017.1404468

Supalla, T., and Newport, E. L. (1978). "How many seats in a chair? The derivation of nouns and verbs in American sign language," in *Understanding Language Through Sign Langauge Research*. ed. P. Siple (Cambridge, MA: Academic Press), 91–132.

Waxman, S. R., and Braun, I. (2005). Consistent (but not variable) names as invitations to form object categories: new evidence from 12-month-old infants. *Cognition* 95, B59–B68. doi: 10.1016/j.cognition.2004.09.003

Waxman, S. R., and Markow, D. B. (1995). Words as invitations to form categories: evidence from 12-to 13-month-old infants. *Cogn. Psychol.* 29, 257–302. doi: 10.1006/cogp.1995.1016

Woodruff Carr, K., Perszyk, D. R., Norton, E. S., Voss, J. L., Poeppel, D., and Waxman, S. R. (2021). Developmental changes in auditory-evoked neural activity underlie infants' links between language and cognition. *Dev. Sci.* 24:e13121. doi: 10.1111/desc.13121

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# Learning a second language *via* print: On the logical necessity of a fluent first language

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How Deaf children should be taught to read has long been debated. Severely or profoundly Deaf children, who face challenges in acquiring language from its spoken forms, must learn to read a language they do not speak. We refer to this as learning a language *via* print. How children can learn language *via* print is not a topic regularly studied by educators, psychologists, or language acquisition theorists. Nonetheless, Deaf children can do this. We discuss how Deaf children can learn a written language *via* print by mapping print words and phrases to sign language sequences. However, established, time-tested curricula for using a signed language to teach the print forms of spoken languages do not exist. We describe general principles for approaching this task, how it differs from acquiring a spoken language naturalistically, and empirical evidence that Deaf children's knowledge of a signed language facilitates and advances learning a printed language.

KEYWORDS

**deafness, signed languages, American sign language, deaf education, literacy**

## Introduction

Can people learn a language from print? Some older students and adults can learn many aspects of a foreign language using study guides, computer tools, and intensive reading (Krashen, 2004). Scholars may deduce the grammar and vocabulary of ancient languages from studying written texts, using methods from historical linguistics (Sauveur, 1878). But can children acquire a language from exposure to print?

Whether and how children can learn language *via* print is not a topic studied by educators, psychologists, or language acquisition theorists (see review in Caldwell-Harris, 2021). Yet consider a specific group of Deaf children, those Deaf children who are profoundly deaf or otherwise unable to acquire fluency in a spoken language *via* audition or lip-reading. These Deaf children are able to learn to read English. When they do, they are learning a language *via* reading, a difficult and mostly unheralded human achievement (see e.g., Hoffmeister and Caldwell-Harris, 2014; Hrastinski and Wilbur, 2016; Koulidobrova et al., 2018; Howerton-Fox and Falk, 2019). These theorists (and others cited in those journal articles) agree that the acquisition route for Deaf children relies on the same skills recruited by those scholars of ancient languages and adults taking intensive foreign language reading courses: fluency in a first language.

## Who are the deaf learners?

We focus on people who must learn the written form of a language, without full access to spoken instruction or conversational interaction, due to deafness. It is useful to differentiate two categories of deaf learners.

- Those for whom amplification and/or cochlear implants supports learning a spoken language, *via* naturalistic interaction or oral speech training.
- Those for whom amplification and cochlear implants are insufficient to allow proficiency in a spoken language.

The second group are the topic of the paper. This is the group who typically learns and uses a signed language as their primary method of communication. For convenience the term Deaf[1] will be used for this group.

To understand pathways to learning English from print, these Deaf children can be divided into two further categories:

- Children exposed to signed language from early childhood due to parental or family use of signed language, or have other exposure (e.g., enrollment in signed language early intervention or preschool program).
- Children with hearing parents who do not have systematic exposure to a signed language in early childhood.

For descriptive convenience we frequently refer to the written language as English and the Deaf persons' native signed language as American Sign Language (ASL), but our concepts apply to the written form of any spoken language and the natural signed language of that community.

# Challenges in learning a language *via* print

We review here three broad difficulties in learning a written language *via* print.

- Human languages didn't evolve to be learned *via* print. The result is that the route to typical first language acquisition, naturalistic learning *via* social interaction, cannot be employed.
- Deaf educators lack time-tested teaching methods for this difficult, little-studied language learning challenge. An implication is that even those Deaf children with signed language fluency will have difficulty in learning an unknown written language.
- Deaf children who grow up with hearing parents may arrive at school to confront English print without a fully developed language.

We discuss each of these challenges in the next three sections.

## How naturalistic language learning succeeds

To demonstrate the extreme difficulties of language learning *via* print, we briefly detour to the case where language learning appears to be the easiest and most automatic: naturalistic first language acquisition *via* social learning.

First language acquisition is marked by rapidity, apparent automaticity, and seeming unstopability (Lee et al., 2009). Everyday observations of this by authors in the 20th century fueled decades of theorizing about innate language-specific mechanisms (Pinker, 2003). Subsequent research and theorizing allowed the magic of childhood language learning to be unpacked into ideas that hold for either a first or second language. The required innate component is the interactional instinct—motivation to attend to communicative signals from caregivers (Lee et al., 2009) and rich social learning (Bates, 1976). The general-purpose cognitive abilities are statistical learning from repeating patterns (Saffran et al., 1996), the mentalizing ability of attending and inferring other's goals, possibly aided by the mirror neuron systems; and the ability to map symbols to meanings (Bates, 1976). These are summarized in the left-hand panel of Table 1.

The final piece of magic in naturalistic learning in childhood is that language directed to infants and toddlers is simple in vocabulary and grammar, repetitive, and refers to the concrete here-and-now (Bates, 1976). The communicative intent of the words (or signs) of early language is sufficiently simple that the meaning is understood from the context, such as questions about the infant's wants and needs; descriptions of on-going events. This results in what Krashen (1985) called "comprehensible input." Krashen's proposal, now widely accepted, is that for language-meaning mappings to occur, the language encountered must be comprehensible, i.e., the meaning is apparent from on-going interaction. Older children and adults have more difficulty learning a new language because the language they encounter is appropriate for their age, making it abstract and complex.

Even when the context is ambiguous, humans of all ages have a mechanism to aid in mapping language to meaning: they skillfully track interlocutors' intent (Moore et al., 2015). By using knowledge of human-typical goals, young children can frequently guess the meaning of an unknown word, as in fast-mapping. As an example (see Carey, 2010), preschoolers inferred that the novel word *chromium* must refer to the color olive, when

1 The capital "D" in Deaf is typically used to refer to those who identify as members of the Deaf Community and in most cases use a Signed Language.

TABLE 1 What is necessary for naturalistic language learning; when it is present in learning *via* print.

| Learning a first or second language naturalistically *via* social interaction: activities and abilities necessary for success | Learning a second language learning *via* print when and how are these same activities/abilities possible |
|---|---|
| Observing the social routines that accompany language; Inferring non-verbal behaviors; Tracking others' intentions | Watching video dramas with subtitles. These ideally begin with one-word phase to make input comprehensible. |
| Interactional instinct; desire to communicate; rewards of social interaction | Mostly absent when first using print; texting *via* smart phones or online can mimic conversation and thus can bring social rewards |
| Learning linguistic sequences (natural language' sounds or hand movements) | General purpose pattern extraction mechanisms can apply to printed sequences |
| Mapping comprehensible input to mental concepts | Mapping printed words on consumer packaging to items in the package; Understanding placards on buildings; Picture books. |

they were asked, "Bring me the chromium one, not the red one" (gesturing at a plate with a red and olive cup).

## Learning outside of a social context

We now return to learning a second language from print. Printed forms rarely accompany social interaction. Text is symbolic and disembodied. Therefore, the meaning of print forms can't be inferred from the non-verbal social interactions. How can the meaning of printed words be inferred? There is one easy, efficient method: the logic of printed words' meanings and the grammar governing the logic of words' sequences must be explicitly explained. A fluent language can be used by bilingual parents and teachers to explain meanings, polysemic structure and grammatical structure, as occurs in class-room foreign language teaching.

If no fluent language is available to explain the meanings of print words, how can those words be linked to conceptual structures (to meanings)? How can printed forms be grounded (and thus embodied) in non-linguistic experiences? Deaf educators have grappled with this for years, while avoiding the answer of immersing Deaf children in a signed language prior to print exposure (Lane, 1992). For example, Van Staden (2013) describes a vocabulary intervention to boost Deaf children's ability to grasp and retain the meaning of English print words. Her project involved students at a residential school for the Deaf in South Africa. The school had a bilingual signed language policy, with South African Signed Language (SASL) taught alongside written English. English print vocabulary was explicitly mapped to SASL signs, using the techniques of "sandwiching" and "chaining." The first of these is a sequence where the printed word is 'sandwiched' between the signed language equivalents. Chaining is where the print form occurs repeatedly with different translation equivalents that may be meaningful to the learner, such as a signed form or a finger-spelled variant (Humphries and MacDougall, 1999). These techniques are used with the hope that children will infer meaning identity from the rapid juxtaposition of these symbols (Swanwick, 2016). Van Staden's (2013) intervention included additional multimodal methods such as tracing words on sandpaper, creating clay models of the words and their meanings, sorting vocabulary cards into different semantic categories, signing stories from a print book, and picture/word/sign matching exercises. These methods do make sense in terms of trying to press sensory-motor association onto lifeless graphemes.

From the standpoint of typical second language acquisition, these methods are time-consuming and cumbersome. Sandwiching is reminiscent of Helen Keller's insight when her teacher finger-spelled "W-A-T-E-R" into Keller's hands while holding her hands under running water. If children were fluent in ASL, teachers could directly state the meaning equivalency using learners' fluent language, as is the norm in any second language learning situation. With a fluent first language, learners could be informed of the approximate signed translation of the target printed word, along with any pragmatic differences or polysemic variations.

## Can printed language be given a social-communicative context?

We've argued that the print form of a language is difficult to learn because print occurs outside of social interaction. Without words being grounded in human activities, words remain disembodied marks on paper. The key remedy, as we just remarked above, is explicitly teaching meanings of print words using a fluent language. However, print does exist in areas where its meaning can be inferred from context. Examples are printed words in picture books, on consumer goods, on placards on buildings, subtitles in movies, and in texting conversations on smart phones and computers. Educators and parents do draw on these, such as innovations in using texting to build vocabulary (e.g., Li et al., 2017), but educators could explore techniques to do more.

Table 1 lists four key activities that allow learning language *via* social interaction, with the right-hand column indicating what could occur for printed language. Social context or any non-verbal context is typically absent from print forms, with exceptions noted in Table 1. The social rewards of conversation are key motivations for language learning (Lee et al., 2009), but these are mostly absent with print forms. However, conversational texting with smart phones provides some of these social rewards, and is motivating for students even when smart phones are used for school-related subjects (e.g., Li et al., 2017).

A drawback is that when conversing *via* smart-phone, interlocuters are usually not co-located, and thus do not share a non-verbal context. This lack of shared context reduces whether the phrases in a typical text-based context are comprehensible input, in the sense of Krashen (1985). If meaning is not comprehensible from context, that reduces opportunities for language learning.

Whether conversational texting could be a source of language learning akin to live social interaction has not been studied. One step would be to measure how frequently smart phones users provide each other with comprehensible input. Research on this topic could open doors for texting to be a vehicle for language learning for Deaf youth.

## The difficulty of learning ancient languages

One well known example of learning a foreign language *via* print concerns learning an ancient language. Scholars have fulminated about the difficulty of this task for centuries. In 1867 John Stuart Mill wrote about the "…shameful inefficiency of the schools, public and private, which pretend to teach Greek and Latin, and do not… criminal idleness and supineness which wastes the entire boyhood of the pupils…" (cited in Sauveur, 1878, p. 4–5). Journals such as *The Journal of Classics Teaching* continue to lament this difficulty. Bracke (2015) celebrates the intellectual value of teaching Greek and Latin to youth, but soberly notes that few students succeed. "For, much as I love ancient languages, I do not think they are for everyone… and the impact learning any subject has on pupils more often results from the teacher than from the subject." She further asks, "Once a school is willing to commit to the ideology of Latin should it be offered to all pupils or only to the Gifted and Talented?" Similar themes occurred in Zeps (2010) essay titled *The Learning of Ancient Languages as (Super) Human Effort*. Zeps (2010, p. 2) laments how rare it was for any of his students to succeed, noting, "…students with excellent memory and other gifts, namely, they very easily go forward in language, but in the end, they lose interest and go astray."

We cite this literature as evidence of the difficulty of learning languages *via* print, not its impossibility. Students can learn ancient languages, which they do *via* carefully designed instruction and their fluent first language. But note that a Deaf student learning English *via* print has a big advantage over a hearing student learning Latin: the motivation of real-world relevance. As occurs with immigrants, another highly motivated group, learning the written form of their country's majority language is a route into connecting with wider professional, intellectual and cultural life. The student of Latin can give up and pursue a different hobby or career goal.

Scholarship also exists on Deaf students learning ancient languages. Buchholz (2017, p.) argues: "… to better teach ancient languages to Deaf students, a new pedagogical approach is needed. Deaf ancient language students, who are naturally visual and acquire their first written language by eye, need to be exposed to ancient languages visually. Such an approach requires a lot of collaborative work among ancient language scholars and teachers who are also skilled in ASL to develop ancient language instructional materials for Deaf students." This echoes our argument, that a fluent signed language and innovative instruction are needed to teach an unknown written language. Signed language use is also advocated for teaching Deaf students foreign languages in general (Piñar et al., 2008).

## How does learning proceed in the absence of a curriculum to teach language *via* print?

Our focus in this section is on children growing up with a signed language in the home, as is often the case with Deaf parents or Deaf family members.

Deaf children of Deaf parents get exposed to printed language in both uninstructed and instructed contexts. Deaf parents typically provide signs for words printed in children's books, and on consumer goods around the house, such as *cereal, popcorn, candy, cookie* (Maxwell, 1984; Schleper, 1997; Rottenberg, 2001; Berke, 2013). In classrooms, teachers frequently provide ASL translation equivalents for words and sentences in printed classroom materials.

When persons outside of the Deaf world observe Deaf children productively interacting with English print in these cases, it is natural to assume that Deaf children are conceptualizing the print forms as English and are thus learning English. This assumption is often incorrect. To make sense of inert printed sequences, those sequences must be mapped to internal meaning structures. Deaf children will frequently do what foreign language learners do everywhere: translate the foreign word to known vocabulary. Deaf children thus map printed words to signs (Maxwell, 1984). For the case of ASL, ASL is an SVO language like English. The structure represented in simple print sentences can then also be mapped to ASL grammatical structures.

We previously described three stages we observed Deaf children progressing through as they grappled with obtaining meaning from print (Hoffmeister and Caldwell-Harris, 2014). These are:

Stage 1: Mapping lexical signs (simple translation equivalents).
Stage 2: From words to sentences: simple translation breakdown.
Stage 3: Bilingual learning mode.

*Stage 1.* In the initial stages of exposure to print, high frequency, short print words are mapped to their ASL equivalents. The similarity in meaning and frequency between English and ASL forms determines how easily these mappings are retained. For children with a rich L1 and patient adults who provide mappings (or access to sign print books), the initial stage of learning can be heady, with rapid acquisition of many translation equivalents (e.g., Schleper, 1997). But learners may initially make progress by perceiving print to be a system for writing ASL on paper.

*Stage 2.* The direct mapping strategy is inadequate because single words and signs are frequently not simple translation equivalents.

The big-picture goal is for learners to realize that English has unique methods for conveying meaning that need to be learned on their own, not as translations in ASL. This is the stage where children can stall in their reading progress because of the inherent difficulty of figuring out function words, polysemic variations and English syntax. Academic failure and dislike of reading are likely outcomes.

Individuals with innate linguistic aptitude can often grapple successfully with complex mappings. Another route is to engage Deaf parents or other mentors in dialogue about the workings of English vocabulary and grammar (Schleper, 1997).

*Stage 3.* Once learners understand that English print constitutes a separate language from ASL, and have a lexicon of basic mappings, they can proceed in a bilingual learning mode, such as Cummins' (2017) comparative learning process. Learners can understand translation-inequivalence, infer meaning of new words from context (Drasgow, 1993), and make analogies to ASL morphosyntactic and metalinguistic knowledge (Czubek, 2021). Perhaps most importantly, learners' fluent first language can be used as the medium of instruction for teaching English polysemy and morphosyntax (DiPerri, 2021).

## Evidence for the descriptive model and implications

Evidence for direct mapping comes from longitudinal case studies of how individual Deaf children used signed language as part of learning to read (Maxwell, 1984; Rottenberg, 2001; Berke, 2013). Maxwell (1984) documented how Alice, a Deaf girl born to Deaf parents, interacted with picture books from age 2 to 6 years of age. Alice spent her early years first signing with her parents about the content of the story. As the years went by, Alice used ASL to add her own material about the story. Alice was especially intrigued by sign print books, which are traditional picture books illustrated with signs in Signed English or in ASL (sign print books have long been published by Gallaudet University Press). Alice's father frequently pointed to print words, provided the ASL sign for them, and finger-spelled words and proper names. Alice was eventually observed doing this herself. She would sign the ASL translations for English words, reading a story by translating it into ASL.

> After age 4 Alice began to read more non-signed print books and to make signs for the English print words. Her reading of both Sign print and English print tended to be word for word and labored. Enormous concentration would be marshaled as Alice centered a page in front of her and gazed at it. By this time she read in sequence, though with frequent omissions (Maxwell, 1984, p. 208).

Rottenberg's (2001) case study also noted the early importance of Deaf children mapping print words to sign language or sign print:

> As Jeffrey gained proficiency in one-to-one matching of sign print to written English, he began to rely on the sign print only if he could not gain meaning from the written English (Rottenberg, 2001, p. 274).

Other evidence that print words are mapped to signed language comes from in-depth interviews with Deaf adults. Those who were categorized as good readers reported that they learned to read by translating English print to ASL (Silvestri and Wang, 2019). Many noted that even as adults they mentally translate complex English print structures to ASL.

It has become well-known that Deaf readers activate the ASL translations of written words (Morford et al., 2011). This occurs for both middle-school (Villwock et al., 2021) and adult readers (Morford et al., 2017). As Morford et al. (2011) note, mentally activating an additional language while reading a different language is a common occurrence for bi- and multi-lingual persons. Proficient Deaf signers are thus typical bilinguals in this regard.

Berke (2013) observed Deaf parents using ASL to aid their Deaf children to move beyond transparent mappings.

> Deaf mothers intuitively know that words in English may not have the same connotation in ASL. Whether or not they had training in deaf education, mothers provided an explanation of how one English word could have different ASL meanings (Berke, 2013, p. 304).

This descriptive model describes the rapid success at stage 1, which is mapping translation equivalents. Where learners typically get stuck is stage 2, when simple mappings are insufficient. We argued that this is where explicit guidance can set a learner on the path to fully learning a language from its print form. Consistent with this point are the cases studies in which Deaf parents closely guided their children (Maxwell, 1984; Rottenberg, 2001; Berke, 2013). Details are scarce about whether parents used examples of ASL morphosyntax and polysemous vocabulary to teach English morphosyntax and polysemous vocabulary (stage 3). One example comes from Schleper's (1997) summary of strategies used by Deaf parents to foster their child's literacy development. Picture books for young children typically have repeated phrases, as in "He huffed, he puffed..." in The Three Little Pigs. Deaf parents would vary how they signed repetitive phrases. This variation in signing allowed their Deaf child to learn that while the English text remained constant in the book, the meaning could be signed in different ways. This demonstrated linguistic creativity, while also being a strong signal that print and ASL are separate languages.

*Summary.* The descriptive model is not a curriculum or even advice on how to teach Deaf children the print form of a language. Instead, these stages summarize what frequently occurs without a curriculum and with only informal teaching. The sobering implication is that Deaf children are too often on their own to figure out English *via* print. Lacking advisors and instruction on the logic and purpose of grammatical markers in the written language, common outcomes are stalled and non-proficient print reading (Caldwell-Harris, 2021). For example, some orally-trained Deaf adults who had become fluent signers and proficient readers used a semantic key-word strategy for reading in which much grammatical structure was ignored (Domínguez et al., 2014). The descriptive model is thus relevant to explaining both Deaf reading success stories and the average low achievement levels of Deaf students (Lane et al., 1996).

## The challenge of language deprivation

Learning a language *via* print is challenging even when Deaf children arrive at school with proficiency in a signed language. Consider the situation of Deaf children who do not have early exposure to a signed language. Even with caring family members and physical comforts, language deprivation occurs (Humphries et al., 2014). Language deprivation means fewer age-typical opportunities for cognitive and social development. The educational consequences of this have been extensively described for many decades (e.g., Lane, 1992; Drasgow, 1993). Language deprivation impacts school readiness, which in turn sets up children for disliking school, school failure, and behavioral challenges (Johnson et al., 1989), including maladaptive behavior (Stevenson et al., 2010).

Children who have been taught *via* speech training and oral methods in regular hearing school programs sometimes do not succeed in acquiring a spoken language, resulting in low educational achievement. Parents and educators at that point see the grave need for exposure to signed language. When sent to a school for the Deaf they may be in middle childhood and delayed in all school topics (Henner et al., 2016). Deaf schools must thus teach both children with excellent language skills and those with practically none, which constitutes another challenge for these schools.

# Foundational principles for teaching a written language using a signed language

The most important principle is that proficiency in a signed language must come before a child is required to learn written forms. Exposure must be as early as possible, ideally, from infancy. The primary reason is forestalling and remediating language deprivation, given the grim outcomes described in the prior section. A secondary reason is that a proficient language can efficiently scaffold teaching of a printed language. Teachers of the Deaf need to be knowledgeable and proficient in the signed language used in the classroom. More broadly, attitudes about Deaf education among professionals and society at large need to change.

## Early access to signed language reduces language deprivation

The primary purpose of early exposure to a signed language is humanitarian: to forestall language deprivation (Humphries et al., 2014), as discussed earlier. A welcome side-effect of providing early language access is that the social and cognitive benefits of early language radiate out to improve every aspect of life, including having a language for classroom communication (Johnson et al., 1989; Wilkinson and Morford, 2020).

A route for ensuring early signed language is *via* programs where deaf children acquire a signed language in a natural environment as soon as possible (Snoddon, 2008; Corina and Singleton, 2009). Current policies in schools and programs serving Deaf children in the US[2] are guided by an audiological model where "speech" and "audition" are the focus. As soon as an infant is identified as Deaf, audiologists are notified and recruited to design and implement a treatment plan for the infant. A parallel notification system can be instituted by contacting local agencies of Deaf professionals who will reach out to the family and provide guidance regarding ASL training XXX. This was accomplished *via* the "ASL models program for families" program, which was carried out in Scranton, PA and in Philadelphia, PA and eastern Massachusetts[3]. Fluent ASL users

2 And unfortunately throughout the world.

who were Deaf were trained to work with non-Deaf parents and their Deaf children in the home. These fluent ASL users usually worked with parents and their Deaf child for 10–20 h a week. For parents who needed to work, the program functioned in part as day care services. By allowing time each week for parents to interact with the ASL model, ASL could be learned by parents, focusing on those signed sequences useful in early parent-infant interaction.

An ASL Models Program at the Scranton State School for the Deaf was embedded within the school program and lasted seven years until the school closed. Students who participated in the program for more than 5 years made significant gains in their ASL knowledge and in reading scores (Hoffmeister et al., 2003). A corollary to the idea of Deaf signers who visit the home is to hire Deaf teachers in preschools (Shantie and Hoffmeister, 2000). Abrams et al. (1996) described a preschool class where Deaf and hearing teachers co-teach, using a whole-language approach to build student ASL vocabularies and written English skills. Snoddon (2015) and Oyserman and de Geus (2021) discuss programs to teach signed language to parents of Deaf children.

## Signed language must come before print

In a bilingual program, the written language and signed language should not be introduced at the same time or taught as if they have equal status. Proficiency in a first language is necessary before learning and teaching a written language.

This principle was recognized by early advocates of using ASL to educate Deaf students in the US (e.g., Johnson et al., 1989; Drasgow, 1993; Hoffmeister, 2000; Wilbur, 2000; Goldin-Meadow and Mayberry, 2001; Supalla et al., 2001). Drasgow (1993) raised the question of how a bilingual program for Deaf students should be structured, reviewing three approaches. In an English-centered approach, English is the primary language, but ASL is used to clarify, to explain difficult material or to answer students' questions. In the second method, English and ASL are equal in the bilingual classroom from the earliest grade levels, with both being used and taught at the same time. Drasgow's (1993) third method is what we are recommending here: A natural signed language needs to be learned first, and learned to interactive fluency, and then used as the medium of instruction for teaching the written language.

Why isn't the second method the best? Teaching English and ASL simultaneously as equivalent languages, with equal status in the classroom, is possible after proficiency is attained in both languages. But equal status *in the early years* has the following drawbacks.

Children will be expected to perform the difficult (and often impossible) task discussed in the prior sections. That is, the task of extracting meaning from print, without a proficient language for basic communication and explanation of the meaning of print forms.

Treating a natural signed language and a written language as having equal status ignores how the two languages can be learned using different methods. Written English must be taught explicitly. A signed language can be learned *via* naturalistic social interaction. Not taking advantage of this means missing out on the social interaction magic that makes learning rewarding and builds native-speaker proficiency at the same time as social skills.

Granting ASL and English similar status obscures the different purpose of the two languages. The former is used to scaffold learning of the latter, and for general classroom communication. Once students have gained proficiency in the written language, it can be used as a second communication mode in the classroom, or even as the primary language for school-based information.

## Avoid teaching words' sounds and focus on words' meanings

Although spoken-word phonology is crucial for learning to read (Dehaene, 2009), knowing the sounds of words and graphemes is not necessary when learning a language *via* print. Humans can read without activating words' spoken phonology, using mappings that extend directly from graphemes to lexical identity and meaning (Bowers and Bowers, 2018). Phonological activation is reduced when typical hearing readers developed high reading skill. Readers frequently skip the step of phonologically decoding difficult words, because it is more efficient to access meaning directly *via* the semantic pathway (Dehaene, 2009; Bowers and Bowers, 2018). Low or no activation of spoken phonology frequently occurs when reading Chinese, since cues to pronunciation are absent or unreliable in 2/3 of characters (Cheng and Caldwell-Harris, 2011). However, note that some Deaf learners do use signed language phonology when trying to understand print (DiPerri, 2021).

Many Deaf learners may desire speech training in order to participate in spoken conversations. But if the goal is reading and writing proficiency with little or no spoken interaction, then early, lengthy training on grapheme-to-spoken phoneme correspondences is misplaced time and effort.

Ignoring spelling-to-sound patterns is especially efficient for irregular orthographies like English. Bypassing this time-consuming part of learning to read allows more time for mapping between orthography and meaning. However, without

3 Many of the participants continued on to college and university. Two participants in the ASL models program in Massachusetts continued at the Learning Center for the Deaf, Framingham, MA and graduated from Princeton University. Fluent in ASL one is an architect (Mansfield, J.), and the other is pursuing a PhD in theoretical physics at the U of Illinois (Lualdi, C.).

mapping syllables to their sounds, Deaf individuals must memorize arbitrary strings of letters, a difficult task. One strategy is to focus on subparts of words that are meaningful: the words' morphology. Learning the meaning of letter clusters like *un, re* and *ment*. Indeed, English privileges retaining morphology over regular spelling-to-sound rules, such that the morpheme *heal* is retained in the noun-form *health* despite the difference in pronunciation. Instructional time freed-up by ignoring spelling-to-sound patterns can be turned over to learning morphology, knowledge that will aid English mastery.

Consistent with this advice, skilled Deaf readers tend to have good command of English morphology (Clark et al., 2011). Interventions to teach Deaf children morphology have improved reading comprehension and writing skills (Nunes et al., 2010).

## Fluent signing is not enough for learning a print language

Knoors and Marschark (2012) observed that signed language aids Deaf children initially by building reading/print vocabularies, but long-term reading for meaning achievement remains elusive. Those authors wrote, "…stagnation occurs, and the reading skills tend to lag or asymptote…" (p. 297). The implication of this comment is that proficient signing is not the magic remedy that will confer grade-level reading skills on Deaf children. We concur. Proficient signing is necessary but not sufficient. Novel curricula are needed, not methods adapted from the hearing curriculum (Lane, 1992; Greenwald, 2021).

Additional challenges involve the knowledge and quality of signed language used at schools and programs serving Deaf students. Historically, teachers lacked basic signed language proficiency and even schools for the Deaf avoided hiring Deaf teachers (Corbett and Jensema, 1981), leading to a literature on why Deaf schools should hire Deaf teachers (e.g., Shantie and Hoffmeister, 2000; Andrews and Covell, 2006)[4]. Teachers also usually present academic material at their own level of fluency and frequently must focus on the lowest achieving students in their class. Schools have the challenge of working with children who have suffered varying levels of language deprivation, with consequent low experience of academic success, poor academic skills and dislike of school (Henner et al., 2016).

Innovative teaching methods must be centered around signed-language use for Deaf students. Here we note a few recent examples of these. Kourbetis and Karipi (2021) developed tools to teach Greek Signed Language to both deaf and hearing learners (see www.sign1st.eu). The Bilingual Grammar Curriculum (BGC) developed by Czubek (2021) and DiPerri (2021) uses ASL to teach about ASL and used ASL to teach the structure of English. Another type of innovation centers around writing systems for ASL. The ASL-phabet uses a limited set of letter-like graphemes to depict ASL phonological features (Cripps et al., 2020). Another writing tool is ASL glossing, a system of using English printed words with additional notation to write the content of an ASL sentence (Supalla and Byrne, 2018; Cripps et al., 2020). This builds on students' established L1 fluency. One goal for future research is to systematically identify, compare and evaluate novel teaching methods.

The next section sets out what evidence exists to support these principles.

## Evidence about signed language use, academic achievement and reading outcomes

We first review two reasons why many researchers believe the opposite of our argument, and why many researchers believe that using a natural signed language detracts from success in reading.

### High variability in hearing abilities and reading success

Some hard-of-hearing and Deaf children can acquire basic or even good English speaking and comprehension skills *via* speech training, amplification and/or cochlear implant. Educators who use traditional instruction observe many of these children succeeding in a mainstream classroom. Such powerful personal observations invite the inference that great educational effort on the part of speech pathologists, teachers and Deaf children will lead to eventual reading success. The Deaf children and their special education team just need to keep trying. People may also focus on success stories and disregard failures, especially when failing students transfer out of a mainstream school to attend a Deaf school.

As we describe below, actual studies, not just observations, also lead to powerful, incorrect inferences.

### In no research are deaf children randomly assigned to a language learning method

Over the decades, researchers have frequently analyzed English reading scores for Deaf children who learned only spoken English, comparing them to children who signed and had little to no spoken English. This would seem to be the data that would settle the question of which method is the best. Lederberg et al. (2013) and Antia et al. (2020) made this

4 Schools are now eager to hire Deaf teachers, but Deaf teachers are in short supply (https://www.deafjobwizard.com/post/overcoming-shortage-of-teachers-of-the-deaf-and-hard-of-hearing).

comparison in several recent studies. A third group used both spoken English and signing. The outcome was unequivocal: markedly higher reading scores for the speaking-only group at every age tested (see illustrative graphs in supplementary files in Antia et al., 2020).

The conclusion appears unassailable: get your Deaf child in a spoken English program if you want good English reading ability. Given that the speaking-only group in the research by Antia et al. (2020) had superior reading ability to the speaking + signing group, an additional inference is to disallow use of signed language. These outcomes, present in decades of data, have long influenced educational policy (Lane, 1992).

Comparisons by Harris et al. (2017) similarly compared Deaf children with different language learning methods. They reported:

> Single word reading improved at each assessment point for the deaf children but there was no growth in reading comprehension from T2 to T3 [from the second to third assessment] ….orally educated children had higher scores than children who signed in the classroom. English vocabulary and speechreading were the most consistent longitudinal predictors of reading for the deaf children. Phonological awareness was the most consistent longitudinal predictor for the hearing group and also a concurrent predictor of reading at T3 for both groups (Harris et al., 2017, p. 233).

The mistake in forming polices based on such studies is that Deaf children are never randomly assigned to sign-only vs. spoken-only language treatments. Instead, some Deaf children have sufficient residual hearing or lip-reading aptitude to succeed in acquiring language from speech. Reading for these children is the traditional hearing process of first naturalistically learning the majority language used in school, and then reading *via* decoding print forms into their auditory forms. In contrast, children in the signing-only group are bilingual, and must learn their second language *via* the written modality.

Do scholars draw unwarranted conclusions from the classroom studies comparing signing-only and orally-trained learners? Consider the following quote from Zhao and Wu (2021).

> A study by Harris et al. (2017) indicated that DHH [Deaf and Hard of Hearing] children who used sign language scored lower than oral language users on many reading measures (Zhao and Wu, 2021, p. 666).

Zhao and Wu (2021) then proceed to problem-solve about why sign language is inferior to oral language for reading. They speculated:

> … the mismatch in grammatical structure between the sign language system and the writing system may be linked to a delay in the reading development of DHH children (Zhao and Wu, 2021, p. 666).

Correlation is not causation. When naturally occurring groups are studied, researchers need to be aware that groups may differ in the abilities (such as residual hearing or speech reading talent) that promote success on the target measure (in this case, reading). Comparing the English reading ability of signing Deaf children to that of typical hearing children, or to Deaf children who have more residual hearing or better access to spoken language, is uninformative about the most helpful route for severely or profoundly Deaf children.

## Early exposure to a signed language

A great deal of evidence has now accrued that early access to a signed language ensures typical child development (Corina and Singleton, 2009). Early age of exposure is also important for developing strong signed language skills (Henner et al., 2016). Strong language knowledge and fluency then aids classroom achievement including reading (e.g., Hrastinski and Wilbur, 2016; Henner et al., 2021; Sehyr and Emmorey, 2022).

Historically, much of evidence that signed language facilitates reading was indirect, in the form of superior reading achievement of Deaf children with Deaf parents, compared to Deaf children with hearing parents (e.g., Moores, 1982 for a review; Strong and Prinz, 2000).

But in the last 15 years, parental deaf/hearing status has been set aside in favor of directly measuring signing ability in children. The overall finding is that signing proficiency correlates with reading skills (see reviews in Chamberlain and Mayberry, 2008; Scott, 2021; Hoffmeister et al., 2022) and general classroom achievement (Hrastinski and Wilbur, 2016). Better reading skills were also found for earlier age of exposure to ASL and earlier entry to a school for the Deaf (Henner et al., 2016).

Establishing these findings required valid, psychometrically sound tests of signed ability which could be easily administered to large number of Deaf children in different geographic areas. Diverse tests were developed in the last two decades (Haug and Mann, 2008) but for years remained limited in coverage and applied to small samples (see review in McQuarrie and Enns, 2021). Robust tests have emerged in the last years, such as ASL-RT (McQuarrie and Enns, 2021) and the ASL Assessment Instrument (Henner et al., 2017; ASLAI, see Costello, 2021).

In the next section we focus on studies using the ASLAI.

## Evidence on ASL facilitating English literacy

Considerable data now documents that ASL knowledge facilitates English literacy. In an early study, Hoffmeister (2000) assessed 78 deaf students, aged 8–15, using tests of ASL synonyms, antonyms, rare vocabulary, and plural knowledge. These vocabulary measures correlated with reading comprehension abilities, measured using the Reading Comprehension subtest of the Stanford Achievement Test (SAT-RC), and the Rhode Island Test of Language Structure (RITLS). Those early vocabulary tests were later developed into what is now the ASL Assessment Instrument (ASLAI).

The ASLAI is a receptive, computer-based testing battery for measuring ASL knowledge without using English print (Henner et al., 2017). Participants take the ASLAI in front of a computer, guided through tasks by instructional ASL videos. The general testing format is multiple choice task using an ASL video or a pictured object, or a signed stimulus and four subsequent signed ASL responses. Test takers select a response by clicking on a button or in the current iteration using a touch screen. Our team's method was to test whole populations in schools, using schools for the Deaf across the US.

A large database of test-takers allows multiple-regression to identify factors that impact reading ability (Scott, 2021; Hoffmeister et al., 2022). Novogrodsky et al. (2014) conducted multiple regression on reading comprehension scores across Deaf children aged 4–18, using predictors of ASL knowledge of antonyms, age, and parental hearing status (Deaf or Hearing parents). Antonym knowledge in ASL predicted 35% of the variability of reading comprehension scores. ASL antonym knowledge eliminated the advantage of Deaf parents for reading. This is both theoretically and practically important. It strengthens the conclusion of a causal relationship between ASL skills and reading. Hearing parents can be alerted that helping their Deaf child acquire signed language can boost cognitive development and school achievement (see Hall et al., 2019).

Many studies use measures of signed language vocabulary when testing signing-reading relationships, but a special role for knowledge of signed language syntax has recently been documented. Understanding the syntax of written languages has long been noted as a challenge for Deaf individuals (e.g., Domínguez et al., 2014; Antia et al., 2020). A group of orally-trained Spanish Deaf students were found to mostly ignore syntax, relying on semantic key words to gain meaning (Domínguez et al., 2014; see earlier mention of this study and discussion in Caldwell-Harris, 2021).

According to the ideas presented here, Deaf students growing up with strong signing skills should be better prepared to learn a written language, including its syntax. Hoffmeister et al. (2022) used knowledge of ASL vocabulary and syntax to predict knowledge of written English syntax (using the RITLS). These 517 participants were 7–18 years of age, and 34% were native signers, defined as having at least one Deaf parent. The two ASLAI vocabulary measures (Synonyms and Antonyms) correlated with English reading comprehension (SAT-RC) with $r$ values of $r = 0.51$ and $r = 0.54$. The ASL vocabulary correlations with English syntactic ability (RITLS) were $r = 0.62$ and $r = 0.65$. Hoffmeister et al. pursued a unique analysis in which the 4 quantiles of English language ability levels were separately analyzed. Knowledge of ASL syntax predicted knowledge of English syntax for each of the four ability levels. Also striking was how analogical reasoning in ASL was associated with English reading at every ability level. These results are strong support for cross-linguistic, cross-modality transfer in the domains of understanding English print including understanding English syntax.

The findings reviewed here parallel other studies showing relationships between ASL lexical knowledge and print decoding skills (e.g., Mayberry et al., 2011; Hrastinski and Wilbur, 2016; see also Hermans et al., 2008 for correlations between Signed Language of the Netherlands and reading Dutch).

## Conclusions

Of the three types of bilingual curricula discussed by Drasgow (1993), the optimal method is to allow natural learning of signed language first, and then use signed language to teach the written language. This is the least frequently implemented method in the US and many other countries. Privileging dominant spoken languages has been standard practice for centuries (Lane, 1992; Lane et al., 1996; Greenwald, 2021). Because of this, Deaf students in the US experience a spoken English-centric education (Singleton and Meier, 2021), or are exposed to ASL and English simultaneously (see reviews in Howerton-Fox and Falk, 2019). This likely reflects cultural imperialism, viewing "deafness as deficient" (Cripps et al., 2020) and viewing signed languages as inferior to spoken languages (Henner and Robinson, 2021).

The point we have argued is a logical one, although also consistent with empirical data, reviewed in the prior section. No human can learn the print form of a novel, unknown language without using a known language to explain the vocabulary and grammar of the novel language. The logical result for Deaf children is that signed language must be used as the base language for learning. Does anyone not accept this logic? Cripps et al. (2020) note that indeed, consensus is lacking. They cite Luckner (2013), an expert in deaf education, who wrote: "…research demonstrating that deaf students who are deaf or hard of hearing develop reading skills differently from typical hearing students has not been produced…" (Luckner, 2013, p. 15).

Lack of consensus may occur because researchers vary whether their reference group is Deaf children who can gain information from speech vs, those Deaf children who cannot acquire spoken language (Napoli et al., 2015). Does our position of "signed languages before spoken/written languages" thus only hold for those Deaf children for whom amplification and speech training fails to deliver proficiency in a spoken language? No. All Deaf and hard-of-hearing children can benefit from exposure to signed languages from birth.

To summarize the benefits of early exposure to signed languages:

- Bilingualism from birth is an advantage for children regardless of hearing status (D'Souza et al., 2020).
- While many Deaf and hard-of-hearing children may eventually do well in acquiring spoken language, no disadvantages occur for learning signed language while also being exposed to a spoken language *via* amplification or cochlear implants (Davidson et al., 2014).
- It is impossible to predict which Deaf children will eventually succeed with spoken language (Szagun and Stumper, 2012; Napoli et al., 2015).
- Because spoken language access is unreliable and requires intense investment, Deaf children need early access to signed language for basic cognitive and social development (Humphries et al., 2016; Swanwick, 2016).
- To eliminate language deprivation and increase academic achievement for Deaf individuals, the key path forward is to build consensus among Deaf educators to foster early signed language use.

English-centric Deaf education must be set aside. The field of Deaf education can elaborate views of Deaf education that are rooted in signed language, as described above and elsewhere (e.g., Schleper, 1997; Hrastinski and Wilbur, 2016; Supalla and Byrne, 2018; Hall et al., 2019; Czubek, 2021; Kourbetis and Karipi, 2021; Kuntze and Golos, 2021; Pagliaro and Kurz, 2021).

In writing about multicultural education policy in US public schools, Valdés (2021) wrote, "Educating children in a language they neither speak nor understand is an enormous challenge." This is the situation currently facing Deaf children, but worse. The typical hearing immigrant child has a first language that can be used as the basis for learning the second language. Deaf children deserve no less. Proficiency in signed language first, and then a classroom environment in which that fluent first language can be used to tackle the enormous challenge of learning a written language without knowing its spoken form.

## Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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## References


Abrams, M., Weinstock, J., and Erting, L. (1996). Surround them with language. *Perspect. Educ. Deafness* 14, 12–15.

Andrews, J. F., and Covell, J. A. (2006). Preparing future teachers and doctoral-level leaders in deaf education: meeting the challenge. *Am. Ann. Deaf* 151, 464–475. doi: 10.1353/aad.2007.0000

Antia, S. D., Lederberg, A. R., Easterbrooks, S., Schick, B., Branum-Martin, L., Connor, C. M., et al. (2020). Language and reading progress of young deaf and hard-of-hearing children. *J,. Deaf Stud. Deaf Educ.* 25, 334–350. doi: 10.1093/deafed/enz050

Bates, E. (1976). *Language and Context: The Acquisition of Pragmatics*. Cambridge, MA: Academic Press.

Berke, M. (2013). Reading books with young deaf children: strategies for mediating between American Sign Language and English. *J. Deaf Stud. Deaf Educ.* 18, 299–311. doi: 10.1093/deafed/ent001

Bowers, J. S., and Bowers, P. N. (2018). Progress in reading instruction requires a better understanding of the English spelling system. *Curr. Dir. Psychol. Sci*. 27(6), 407-412.

Bracke, E. (2015). Bringing ancient languages into a modern classroom: some reflections. *J. Classics Teach.* 16, 35–39. doi: 10.1017/S2058631015000185

Buchholz, N. D. (2017). Teaching ancient languages to deaf students. *J. Disabil. Relig.* 21, 381–394. doi: 10.1080/23312521.2017.1378954

Caldwell-Harris, C. L. (2021). "Theoretical underpinnings of acquiring English *via* print," in *Discussing Bilingualism in Deaf Children: Essays in Honor of Robert Hoffmeister*, eds C. Enns, J. Henner, and L. McQuarrie (New York, NY: Routledge), 73–96.

Carey, S. (2010). Beyond fast mapping. *Lang. Learn. Dev.* 6, 184–205. doi: 10.1080/15475441.2010.484379

Chamberlain, C., and Mayberry, R. (2008). American Sign Language syntactic and narrative comprehension in skilled and less skilled readers: bilingual and bimodal evidence for the linguistic basis of reading. *Appl. Psychol.* 29, 367–388 doi: 10.1017/S014271640808017X

Cheng, H., and Caldwell-Harris, C. (2011). "When semantics overrides phonology: Semantic substitution errors in reading Chinese aloud," in *Paper* *presented at the 85th Annual Meeting of the Linguistic Society of America* (Pittsburgh, PA).

Clark, M. D., Gilbert, G., and Anderson, M. L. (2011). Morphological knowledge and decoding skills of deaf readers. *Psychology* 2, 109. doi: 10.4236/psych.2011.22018

Corbett, E. E., and Jensema, C. J. (1981). *Teachers of the Deaf: Descriptive Profiles.* Washington, D.C.: Gaullaudet University Press.

Corina, D., and Singleton, J. (2009). Developmental social cognitive neuroscience: insights from deafness. *Child Dev.* 80, 952–967. doi: 10.1111/j.1467-8624.2009.01310.x

Costello, P. (2021). "Building the ASL assessment instrument," in *Discussing Bilingualism in Deaf Children: Essays in Honor of Robert Hoffmeister*, eds C. Enns, J. Henner, and L. McQuarrie (New York, NY: Routledge), 199–207. doi: 10.4324/9780367808686-13-16

Cripps, J. H., Supalla, S. J., and Blackburn, L. A. (2020). A case study on accessible reading with deaf children. *Soc. Am. Sign Lang. J.* 4, 36–72.

Cummins, J. (2017). Teaching for transfer in multilingual school contexts. *Biling. Multiling. Edu.* 3, 103–115. doi: 10.1007/978-3-319-02258-1_8

Czubek, T. (2021). "Crossing the divide: the bilingual grammar curriculum," in *Discussing Bilingualism in Deaf Children: Essays in Honor of Robert Hoffmeister*, eds C. Enns, J. Henner, and L. McQuarrie (New York, NY: Routledge), 150–170. doi: 10.4324/9780367808686-10-12

Davidson, K., Lillo-Martin, D., and Pichler, D. C. (2014). Spoken English language development among native signing children with cochlear implants. *J. Deaf Stud. Deaf Educ.* 19, 238–250. doi: 10.1093/deafed/ent045

Dehaene, S. (2009). *Reading in the Brain: The New Science of How We Read*. New York, NY: Penguin.

DiPerri, K. A. (2021). "The bedrock literacy curriculum," in *Discussing Bilingualism in Deaf Children: Essays in Honor of Robert Hoffmeister*, eds C. Enns, J. Henner, and L. McQuarrie (New York, NY: Routledge), 132–149. doi: 10.4324/9780367808686-9-11

Domínguez, A.-B., Carrillo, M.-S., Pérez, M., Del, M., and Alegría, J. (2014). Analysis of reading strategies in deaf adults as a function of their language and meta-phonological skills. *Res. Dev. Disabil.* 35, 1439–1456. doi: 10.1016/j.ridd.2014.03.039

Drasgow, E. (1993). Bilingual/bicultural deaf education: an overview. *Sign Lang. Stud.* 80, 243–266. doi: 10.1353/sls.1993.0004

D'Souza, D., Brady, D., Haensel, J. X., and D'Souza, H. (2020). Is mere exposure enough? The effects of bilingual environments on infant cognitive development. *Royal Soc. Open Sci.* 7, 180–191. doi: 10.1098/rsos.180191

Goldin-Meadow, S., and Mayberry, R. I. (2001). How do profoundly deaf children learn to read? *Learn. Disabil. Res. Pract.* 16, 222–229. doi: 10.1111/0938-8982.00022

Greenwald, B. H. (2021). "Two centuries of deaf education and deaf agency in the United States," in *Discussing Bilingualism in Deaf Children: Essays in Honor of Robert Hoffmeister*, eds C. Enns, J. Henner, and L. McQuarrie (New York, NY: Routledge), 3–16. doi: 10.4324/9780367808686-1-2

Hall, M. L., Hall, W. C., and Caselli, N. K. (2019). Deaf children need language, not (just) speech. *First Lang.* 39, 367–395. doi: 10.1177/0142723719834102

Harris, M., Terlektsi, E., and Kyle, F. E. (2017). Con- current and longitudinal predictors of reading for deaf and hearing children in primary school. *J. Deaf Stud. Deaf Educ.* 22, 233–242. doi: 10.1093/deafed/enw101

Haug, T., and Mann, W. (2008). Adapting tests of sign language assessment for other sign languages—a review of linguistic, cultural, and psychometric problems. *J. Deaf Stud. Deaf Educ.* 13, 138–147. doi: 10.1093/deafed/enm027

Henner, J., Caldwell-Harris, C. L., Novogrodsky, R., and Hoffmeister, R. (2016). American sign language syntax and analogical reasoning skills are influenced by early acquisition and age of entry to signing schools for the Deaf. *Front. Psychol.* 7, 1982. doi: 10.3389/fpsyg.2016.01982

Henner, J., Hoffmeister, J. R., and Reis, J. (2017). "Developing sign language measurements for research with deaf populations", in *Research in Deaf Education: Contexts, Challenges, and Considerations*, eds S. Cawthon, and C. L. Garberoglio (London: Oxford University Press), 141–160. doi: 10.1093/oso/9780190455651.003.0007

Henner, J., Pagliaro, C., Sullivan, S., and Hoffmeister, R. (2021). Counting differently: assessing mathematics achievement of signing deaf and hard of hearing children through a unique lens. *Am. Ann. Deaf* 166, 318–341. doi: 10.1353/aad.2021.0023

Henner, J., and Robinson, O. (2021). Unsettling languages, unruly bodyminds: imaging a crip linguistics. *PsyArXiv, PPR*367363. doi: 10.31234/osf.io/7bzaw

Hermans, D., Knoors, H., Ormel, L., and Verhoeven, L. (2008). The relationship between the reading and signing skills of deaf children in bilingual education programs. *J. Deaf Stud. Deaf Educ.* 13, 518–530. doi: 10.1093/deafed/enn009

Hoffmeister, R., Greenwald, J., Czubek, T., and DiPerri, K. (2003). "Establishing a dual language program for deaf children: What is needed?" in *Paper presented at the Annual Symposium on Language and Education of the Deaf* (Sioux Falls, SD: Communication Services for the Deaf).

Hoffmeister, R., Henner, J., Caldwell-Harris, C., and Novogrodsky, R. (2022). Deaf children's ASL vocabulary and ASL syntax knowledge supports English knowledge. *J. Deaf Stud. Deaf Educ.* 27, 37–47. doi: 10.1093/deafed/enab032

Hoffmeister, R. J. (2000). A piece of the puzzle: ASL and reading comprehension in deaf children. In C. Chamberlain, R. Mayberry, and J. Morford (Eds.), *Language acquisition by eye* (pp. 143–163). Mahweh, NJ: Lawrence Erlbaum.

Hoffmeister, R. J., and Caldwell-Harris, C. L. (2014). Acquiring English as a second language *via* print: the task for deaf children. *Cognition* 132, 229–242. doi: 10.1016/j.cognition.2014.03.014

Howerton-Fox, A., and Falk, J. L. (2019). Deaf children as 'English Learners': the psycholinguistic turn in deaf education. *Educ. Sci.* 9, 133. doi: 10.3390/educsci9020133

Hrastinski, I., and Wilbur, R. B. (2016). Academic achievement of deaf and hard-of-hearing students in an ASL/English bilingual program. *J. Deaf Stud. Deaf Educ.* 21, 156–170. doi: 10.1093/deafed/env072

Humphries, T., Kushalnagar, P., Mathur, G., Napoli, D.J., Padden, C., and Rathmann, C. (2014). Ensuring language acquisition for deaf children: What linguists can do. *Language* 90, e31-e52.

Humphries, T., Kushalnagar, P., Mathur, G., Napoli, D. J., Padden, C., Rathmann, C., et al. (2016). Avoiding linguistic neglect of deaf children. *Soc. Serv. Rev.* 90, 589–619. doi: 10.1086/689543

Humphries, T., and MacDougall, F. (1999). "Chaining" and other links: making connections between American Sign Language and English in two types of school settings. *Vis. Anthropol. Rev.* 15, 84–94. doi: 10.1525/var.2000.15.2.84

Johnson, R. E., Liddell, S. K., and Erting, C. J. (1989). *Unlocking the Curriculum: Principles for Achieving Access in Deaf Education*. Working/Occasional Paper Series, No. 89-3. Washington, DC: Gallaudet Research Institute.

Knoors, H., and Marschark, M. (2012). Language planning for the 21st century: revisiting bilingual language policy for deaf children. *J. Deaf Stud. Deaf Educ.* 17, 291–305. doi: 10.1093/deafed/ens018

Koulidobrova, E., Kuntze, M., and Dostal, H. M. (2018). If you use ASL, should you study ESL? Limitations of a modality-b(i)ased policy. *Language* 94, 99–126. doi: 10.1353/lan.2018.0029

Kourbetis, V., and Karipi, S. (2021). "How can you talk about bilingual education of the deaf if you do not teach sign language as a first language?", in *Discussing Bilingualism in Deaf Children: Essays in Honor of Robert Hoffmeister*, eds C. Enns, J. Henner, and L. McQuarrie (New York, NY: Routledge), 113–131. doi: 10.4324/9780367808686-8-10

Krashen, S. (1985). *The Input Hypothesis: Issues and Implications.* New York, NY: Longman.

Krashen, S. (2004). *The Power of Reading: A Review of Research.* Portsmouth, NH: Heinemann.

Kuntze, M., and Golos, D. (2021). "Revisiting rethinking literacy," in *Discussing Bilingualism in Deaf Children: Essays in Honor of Robert Hoffmeister*, eds C. Enns, J. Henner, and L. McQuarrie (New York, NY: Routledge), 99–112. doi: 10.4324/9780367808686-7-9

Lane, H. L. (1992). *The Mask of Benevolence: Disabling the Deaf Community*. New York, NY: Knopf.

Lane, H. L., Hoffmeister, R., and Bahan, B. J. (1996). *A Journey into the Deaf-world.* San Diego, CA: Dawn Sign Press.

Lederberg, A. R., Schick, B., and Spencer, P. E. (2013). Language and literacy development of deaf and hard-of-hearing children: successes and challenges, *Dev. Psychol.* 49, 15. doi: 10.1037/a0029558

Lee, N., Mikesell, L., Joaquin, A. D. L., Mates, A. W., and Schumann, J. H. (2009). *The Interactional Instinct: The Evolution and Acquisition of Language.* Oxford: Oxford University Press. doi: 10.1093/acprof:oso/9780195384246.001.0001

Li, J., Cummins, J., and Deng, Q. (2017). The effectiveness of texting to enhance academic vocabulary learning: English language learners' perspective. *Comput. Assist. Lang. Learn.* 30, 816–843. doi: 10.1080/09588221.2017.1366923

Luckner, J. L. (2013). Using the dynamic indicators of basic early literacy skills with students who are deaf or hard of hearing: Perspectives of a panel of experts. *Am. Ann. Deaf* 158, 7–19.

Maxwell, M. (1984). A deaf child's natural development of literacy. *Sign Lang. Stud.* 44, 191–224. doi: 10.1353/sls.1984.0001

Mayberry, R. I., Del Giudice, A. A., and Lieberman, A. M. (2011). Reading achievement in relation to phonological coding and awareness in deaf readers: A meta-analysis. *J. Deaf Stud. Deaf Educ.* 16, 164-88.

McQuarrie, L., and Enns, C. (2021). "Assessing ASL: comprehension, narrative, and phonological awareness," in *Discussing Bilingualism in Deaf Children: Essays in Honor of Robert Hoffmeister*, eds C. Enns, J. Henner, and L. McQuarrie (New York, NY: Routledge), 217–228.

Moore, R., Mueller, B., Kaminski, J., and Tomasello, M. (2015). Two-year-old children but not domestic dogs understand communicative intentions without language, gestures, or gaze. *Dev. Sci.* 18, 232–242. doi: 10.1111/desc.12206

Moores, D. (1982). *Educating the Deaf: Psychology, Principles Practices*. Boston: Houghton Mifflin.

Morford, J. P., Occhino-Kehoe, C., Piñar, P., Wilkinson, E., and Kroll, J. F. (2017). The time course of cross-language activation in deaf ASL–English bilinguals. *Biling.: Lang. Cogn.* 20, 337–350. doi: 10.1017/S13667289150 0067X

Morford, J. P., Wilkinson, E., Villwock, A., Piñar, P., and Kroll, J. F. (2011). When deaf signers read English: do written words activate their sign translations? *Cognition* 118, 286–292. doi: 10.1016/j.cognition.2010.11.006

Napoli, D. J., Mellon, N. K., Niparko, J. K., Rathmann, C., Mathur, G., Humphries, T., et al. (2015). Should all deaf children learn sign language? *Pediatrics* 136, 170–176. doi: 10.1542/peds.2014-1632

Novogrodsky, R., Caldwell Harris, C. L., Fish, S., and Hoffmeister, R. (2014). The development of antonym knowledge in American Sign Language (ASL) and its relationship to reading comprehension in English language learning. *Language Learning*, 64, 749-770.

Nunes, T., Burman, D., Evans, D., and Bell, D. (2010). "Writing a language that you can't hear," in *Reading and Dyslexia in Different Orthographies* (New York, NY: Psychology Press), 127–146.

Oyserman, J., and de Geus, M. (2021). "Implementing a new design in parent sign language teaching: the Common European Framework of Reference for Languages (CEFR)," in *Critical Perspectives on Plurilingualism in Deaf Education*, eds K. Snoddon, and J. C. (Weber Bristol: Multilingual Matters). doi: 10.21832/9781800410756-011

Pagliaro, C. M., and Kurz, C. (2021). "Using ASL to navigate the semantic circuit in the bilingual mathematics classroom", in *Discussing Bilingualism in Deaf Children: Essays in Honor of Robert Hoffmeister*, eds C. Enns, J. Henner and L. McQuarrie (New York, NY: Routledge), 187–196. doi: 10.4324/9780367808686-6-7

Piñar, P., Ammons, D., and Montengero, F. (2008). "Incorporating foreign sign language in foreign language instruction for deaf students: cultural and methodological rationale," in *Worlds Apart? Disability and Foreign Language Learning*, eds T. Berberi, E. C. Hamilton, and I. M. Sutherland (New Haven, CT: Yale University Press), 137–150. doi: 10.12987/yale/9780300116304.003.0007

Pinker, S. (2003). *The Language Instinct: How the Mind Creates Language*. London: Penguin UK.

Rottenberg, C. J. (2001). A deaf child learns to read. *Am. Ann. Deaf* 146, 270–275. doi: 10.1353/aad.2012.0107

Saffran, J. R., Aslin, R. N., and Newport, E. L. (1996). Statistical learning by 8-month-old infants. *Science* 274, 1926–1928. doi: 10.1126/science.274.5294.1926

Sauveur, L. (1878). *Introduction to the Teaching of Ancient Languages*. New York, NY: H. Holt.

Schleper, D. R. (1997). *Reading to Deaf Children: Learning from Deaf Adults*. Washington, DC: Laurent Clerc National Deaf Education Center.

Scott, J. (2021). "The relationship between ASL fluency and english literacy," in *Discussing Bilingualism in Deaf Children: Essays in Honor of Robert Hoffmeister* (New York, NY: Routledge), 171–186. doi: 10.4324/9780367808686-11-13

Sehyr, Z. S., and Emmorey, K. (2022). Contribution of lexical quality and sign language variables to reading comprehension. *J. Deaf Stud. Deaf Educ.* 27. doi: 10.1093/deafed/enac018

Shantie, C., and Hoffmeister, R. J. (2000). Why schools for deaf children should hire deaf teachers: a preschool issue. *J. Educ.* 182, 42–53. doi: 10.1177/002205740018200304

Silvestri, J. A., and Wang, Y. A. (2019). Grounded theory of effective reading by profoundly deaf adults. *Am. Ann. Deaf* 162, 419–444. doi: 10.1353/aad.2018.0002

Singleton, J. L., and Meier, R. P. (2021). "Sign language acquisition in context," in *Discussing Bilingualism in Deaf Children: Essays in Honor of Robert Hoffmeister*, eds C. Enns, J. Henner, and L. McQuarrie (New York, NY: Routledge), 73–96.

Snoddon, K. (2008). American Sign Language and early intervention. *Can. Mod. Lang. Rev.* 64, 581–604. doi: 10.3138/cmlr.64.4.581

Snoddon, K. (2015). Using the Common European Framework of Reference for Languages to teach sign language to parents of deaf children. *Can. Mod. Lang. Rev.* 71, 270–287. doi: 10.3138/cmlr.2602

Stevenson, J., McCann, D., Watkin, P., Worsfold, S., Kennedy, C., and Hearing Outcomes Study Team (2010). The relationship between language development and behaviour problems in children with hearing loss. *J. Child Psychol. Psychiatry* 51, 77–83. doi: 10.1111/j.1469-7610.2009.02124.x

Strong, M., and Prinz, P. (2000). "Is American Sign language skill related to English literacy?" in *Language Acquisition by Eye*, eds C. Chamberlain, R. Mayberry, and J. Morford (Mahweh, NJ: Lawrence Erlbaum), 131–141.

Supalla, S., Wix, T. R., and McKee, C. (2001). "Print as a primary source of English for deaf learners," in *One Mind, Two Languages: Studies in Bilingual Language Processing, eds* J. Nichol, and T. Langendoen (Oxford: Blackwell), 177–190.

Supalla, S. J., and Byrne, A. P. J. (2018). Reading, special education, and deaf children. *Soc. Am. Sign Lang. J.* 2, 36–53. Available online at: https://tigerprints.clemson.edu/saslj/vol2/iss1/1 (accessed June 30, 2022).

Swanwick, R. (2016). Deaf children's bimodal bilingualism and education. *Lang. Teach.* 49, 1–34. doi: 10.1017/S0261444815000348

Szagun, G., and Stumper, B. (2012). Age or experience? The influence of age at implantation and social and linguistic environment on language development in children with cochlear implants. *J. Speech Lang. Hear. Res.* 55, 1640–1654 doi: 10.1044/1092-4388(2012/11-0119)

Valdés, G. (2021). "Realistic expectations," in *Transforming Multicultural Education Policy and Practice: Expanding Educational Opportunity*, ed J. A. Banks (New York, NY: Teachers College Press), 239–274.

Van Staden, A. (2013). An evaluation of an intervention using sign language and multisensory coding to support word learning and reading comprehension of deaf signing children. *Child Lang. Teach. Ther.* 29, 305–318. doi: 10.1177/0265659013479961

Villwock, A., Wilkinson, E., Piñar, P., and Morford, J. P. (2021). Language development in deaf bilinguals: deaf middle school students co-activate written English and American Sign Language during lexical processing. *Cognition* 211, 104642. doi: 10.1016/j.cognition.2021.104642

Wilbur, R. B. (2000). The use of ASL to support the development of English and literacy. *J. Deaf Stud. Deaf Educ.* 5, 81–104. doi: 10.1093/deafed/5.1.81

Wilkinson, E., and Morford, J. P. (2020). How bilingualism contributes to healthy development in deaf children: a public health perspective. *Matern. Child Health J.* 24, 1330–1338. doi: 10.1007/s10995-020-02976-6

Zeps, D. (2010). *The Learning of Ancient Languages as (Super) Human Effort.* Available online at: http://dspace.lu.lv/dspace/bitstream/handle/7/1424/ancient.electronic.pdf

Zhao, Y., and Wu, X. (2021). Predicting reading fluency in Chinese Deaf and Hard of Hearing students: contributions of character recognition, expressive vocabulary, and syntactic awareness. *Am. Ann. Deaf* 166 (5). doi: 10.1353/aad.2022.0003

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# Ongoing Sign Processing Facilitates Written Word Recognition in Deaf Native Signing Children

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Signed and written languages are intimately related in proficient signing readers. Here, we tested whether deaf native signing beginning readers are able to make rapid use of ongoing sign language to facilitate recognition of written words. Deaf native signing children (mean 10 years, 7 months) received prime target pairs with sign word onsets as primes and written words as targets. In a control group of hearing children (matched in their reading abilities to the deaf children, mean 8 years, 8 months), spoken word onsets were instead used as primes. Targets (written German words) either were completions of the German signs or of the spoken word onsets. Task of the participants was to decide whether the target word was a possible German word. Sign onsets facilitated processing of written targets in deaf children similarly to spoken word onsets facilitating processing of written targets in hearing children. In both groups, priming elicited similar effects in the simultaneously recorded event related potentials (ERPs), starting as early as 200 ms after the onset of the written target. These results suggest that beginning readers can use ongoing lexical processing in their native language – be it signed or spoken – to facilitate written word recognition. We conclude that intimate interactions between sign and written language might in turn facilitate reading acquisition in deaf beginning readers.

**Keywords: sign language, ERPs, lexical processing, deaf children, reading, German Sign Language (DGS)**

## INTRODUCTION

There is an ongoing debate on how deaf individuals commanding a signed language acquire literacy (Perfetti and Sandak, 2000; Holmer et al., 2016). Written languages typically are based on spoken languages and signed languages do not share relevant phonology or orthography with written languages. Therefore, deaf individuals can typically not use direct form links between sign and written language. Here, we tested whether emerging literacy in deaf children is closely connected to sign language processing at the word level nevertheless. From a neurocognitive perspective, we investigated whether young signers can exploit aspects of rapid sign processing to foster written word recognition and whether they do so similar to young hearing readers exploiting aspects of rapid spoken word processing.

Similar to hearing individuals processing sequentially unfolding speech in an incremental fashion, signing individuals process sequentially unfolding signs gradually. As soon as hearing individuals have heard some speech sounds, they have available memory representations of words that temporally match the input, and they sequentially exclude those words that no longer match the unfolding input thereafter (e.g., Allopenna et al., 1998; Dahan et al., 2001). Although fundamentally different from phonology in spoken languages, signed languages have a sequential, decomposable phonological structure as well. Typically, handshape, location, movement, palm orientation, and non-manual cues like facial gestures (including mouth movements) are considered as phonological sign language units which define individual signs and unfold over time (Sandler and Lillo-Martin, 2006; Papaspyrou et al., 2008; Brentari, 2011). Comparable to listeners recognizing spoken words, signers use the sequential nature of signs to activate corresponding memory representations even before a signer has completed a sign (Grosjean, 1981; Clark and Grosjean, 1982; Emmorey and Corina, 1990).

In hearing readers, incremental processing of spoken words can immediately modulate the processing of written words. Respective processing links between both domains are exemplified by priming studies, which typically combine spoken primes (complete words or word onsets) and written targets (for an overview see Zwitserlood, 1996). A direct repetition of spoken and written words ["pepper" – *pepper* (here and in the following, italics represent written stimulus materials)] immediately facilitates processing of written target words (compared to unrelated prime-target pairs like "pepper" – *window*) in hearing adults (Holcomb et al., 2005) and in hearing children (Reitsma, 1984; Sauval et al., 2017). Facilitated processing has been observed already when only spoken word onsets were presented as primes (e.g., "can" – candy or "ano" – anorak; Soto-Faraco et al., 2001; Spinelli et al., 2001; Friedrich et al., 2004a,b, 2008, 2013; Friedrich, 2005).

Event-related potentials (ERPs) recorded in priming studies indicate that the processing initiated by spoken word onsets taps early aspects of the processing of immediately following written target words in hearing adults. Two ERP deflections are typically obtained when spoken word onsets are used to prime written target words: Prime-target overlap in phonology consistently elicited left-lateralized more positive-going ERP amplitudes (the so-called P350 effect in word onset priming), and reduced N400 amplitudes with central distribution (compared to unrelated targets, respectively; Friedrich et al., 2004a,b, 2013; Friedrich, 2005). Both effects start 200–300 ms after the onset of a written target word, a time window that is associated with access to stored word representations (e.g., Grainger et al., 2006; Holcomb and Grainger, 2006, 2007). Based on the intimate phonological form relationship between spoken and written words in alphabetic writing systems, links between spoken and written language processing might already originate at the level of phonological representations (e.g., Ferrand and Grainger, 1992; Grainger et al., 2006; Pattamadilok et al., 2017), but might also relate to the level of word form representations. The question emerges whether links between written language and sign language, which do not connect via grapheme-phoneme correspondence at the surface level, originate at the level of word form representations as well.

Previous priming research showed that signing adults implicitly activate signs and their respective phonological forms when they are reading written words [e.g., ASL while reading English words: Morford et al., 2011, 2014; Meade et al., 2017; Quandt and Kubicek, 2018; DGS while reading German words: Kubus et al., 2015; Hong Kong Sign Language (HKSL) while reading Cantonese words: Thierfelder et al., 2020]. These studies exploited pairs of written words that were not related in the written or phonological domain in a given spoken language, but shared sign units in a respective sign language, such as MOVIE and PAPER sharing location and handshape in ASL (here and in the following, capitals denote signed stimulus materials), but no speech sounds in spoken English. When deaf signing participants had to detect semantic similarities for pairs of written words, implicit phonological priming of the underlying signs speeds responding and, vice versa, decisions about semantic differences for pairs of written words slowed down when they overlapped in sign phonology (for ASL: Morford et al., 2011, 2014; for DGS: Kubus et al., 2015). In addition, Deaf native signers show phonological similarity effects in ASL when they have to recall lists of English written words (Miller, 2007).

By using online neurocognitive measures, previous ERP studies with signing adults suggested intimate links between sign word processing and the processing of written words. This was attested by unimodal priming studies combining either signed prime-target pairs (Lee et al., 2019; Hosemann et al., 2020) or written prime-target pairs (Meade et al., 2017). In the signed priming studies, phonological relation in the written domain modulated responses to phonologically unrelated sign pairs like BAR – STAR (with no phonological relation in ASL, but phonological relation in written English; e.g., Lee et al., 2019). Here, N400 effects starting 325 ms after target word onset were obtained (however, interpretation of the onset of ERP effects for signed targets is hampered by variation regarding the sequential nature and respective temporal characteristics of the continuously unfolding signs). In priming studies with written stimuli, phonologically and orthographically unrelated written word pairs like *gorilla* – *bath* were related in their sign language translations like GORILLA – BATH (sharing handshape and location in the corresponding ASL signs; Meade et al., 2017). Written prime-target pairs overlapping in sign phonology elicited a N400 effect starting 300 ms after target word onset. In the present study, we tested whether signing children are linking sign word processing to written word processing as early as adult signers do.

So far, very little is known about aspects of sign language processing and their links to reading in children who have acquired a sign language. Two phonological priming studies have suggested that deaf children, who were native signers of the Sign Language of the Netherlands (NGT), applied incremental phonological processing to signs (Ormel et al., 2009) and that signs are tightly associated with written words (Ormel et al., 2012). In their first study, Ormel and colleagues tested 8–12-year-old deaf children with picture-sign pairs. Children were asked whether the picture and the sign matched (picture verification task). Some unrelated sign-picture pairs, such as DOG and CHAIR, shared sign phonology in NGT (location and movement), while other sign-picture pairs were unrelated in that respect. As in previous work with deaf adults, in deaf children implicit phonological priming of the signs inhibited responding in cases where the sign-picture pairs were unrelated. In a follow-up study, Ormel and colleagues investigated 9–11-year-old deaf children in a picture-word verification task. In that study, NGT translation of the Dutch word and the sign for the picture were either phonologically related or not. Again, children indicated mismatches more slowly when word-picture pairs implicitly overlapped in sign phonology (compared to unrelated pairs). Recently, co-activation of ASL and written English in deaf signing children (mean age of 12.9 years) has been investigated by using a semantic judgment task for written words (Villwock et al., 2021). The children were faster to make "yes" decisions (the words are semantically related) when the ASL translations were phonologically related. As in previous studies for deaf adults (Morford et al., 2011), a subset of the presented semantically related and unrelated word pairs shared sign phonology in ASL. Children were faster to respond to written word pairs with phonological relations in ASL. Consistent with the results of Ormel et al. (2012) this indicates that children have sign language phonology available while they are reading.

In the present study, we use online neurocognitive measures to investigate the temporal processing dynamics underlying interactions between sign and written language processing in deaf signing beginning readers. By recording ERPs to targets in word onset priming, we aimed to uncover whether beginning readers use incremental processing of sign onsets (deaf native signing children) similarly to incremental processing of spoken word onsets (hearing children) to foster ongoing written word processing. Deaf and hearing children were matched on reading skills. Deaf beginning readers saw videos of sign word onsets (primes), which were followed by written words (targets). Hearing beginning readers watched and heard a speaker articulating word onsets (primes), which were followed by written words (targets). Both groups were asked to decide whether the written target was a possible German word. The crucial comparison within a group was between responses to targets in the condition where prime and target were related [Overlapping condition; e.g., KU[1] – *Kuchen* (Engl. cake) and "ku" – *Kuchen*, respectively] versus the Unrelated condition (e.g., WE – *Kuchen* and "we" – *Kuchen*, respectively). An example trial (Overlapping condition) with a sign prime with a sign prime, followed by a written word target is provided in **Figure 1**.

Based on earlier studies using spoken-written word onset priming with hearing adults (Friedrich et al., 2004a,b, 2008, 2013; Friedrich, 2005), we expected to find P350 and N400 effects preceding behavioral responses (lexical decisions). If beginning readers exploit ongoing processing in their native language as rapidly as experienced adult readers, ERP effects should start 200 ms after target word onset (for hearing adults: e.g., Friedrich et al., 2004a,b, 2008, 2013; Friedrich, 2005; Grainger et al., 2006; for deaf signing adult readers: e.g., Gutierrez-Sigut et al., 2017).

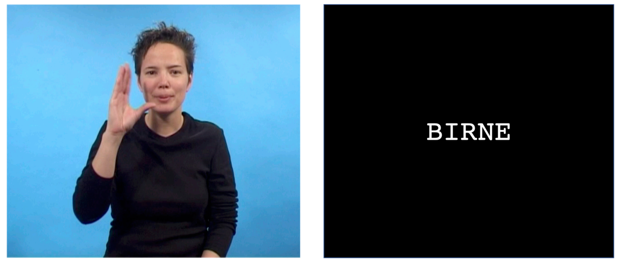


**FIGURE 1** | Illustration of one trial in the overlapping sign fragment – written word condition: The sign fragment "BI" for BIRNE (pear) is followed by the overlapping written word *Birne* (pear).

## MATERIALS AND METHODS

### Participants

Data from fourteen congenitally deaf children (hearing threshold >90 dB in the better ear; seven girls) who had learned sign language from birth from their deaf parents ("native signers") and fourteen typically developing, hearing, children (four girls) with hearing parents ("controls") were included in the study. We recruited deaf children from Schools for Deaf and Hard of Hearing in Germany which ran a bilingual (German and DGS) curriculum at the time. A control group of hearing children was then recruited by matching levels of word reading comprehension across groups. The hearing children were monolingual speakers of German from local primary schools in the city of Hamburg. An additional three native signers and four controls originally participated in the study, but their data could not be included in analyses because of low quality of EEG data as a result of excessive movement by the participant (two native signers; two controls), refusal by the participant to complete the reading test (one native signer), low performance on the reading test (one control) or technical failure during EEG recording (one control). None of the children had any neurological disease or learning difficulties. We obtained written informed parental consent for all children.

Data from native signers was collected first. Based on their performance on a normed German word reading test for beginning readers (ELFE 1–6, word reading comprehension subtest, Lenhard and Schneider, 2006), a younger control group was then recruited to ensure similar levels of word reading comprehension across groups. In this subtest, a picture was presented together with four written words. The child was asked to underline the word that matched the picture. Reported are raw scores, which consist of the total number of correct responses within a time window of 3 min [native signers: $M = 35.9$, $SD = 9.6$; controls: $M = 35.9$, $SD = 7.1$; $t(26) = 0$, $p = 1$, Cohen's $d = 0$]. Note, that the timeline of reading development for deaf and hearing readers differs due to the patterns of language exposure

[1]Sign fragments such as "KU" for KUCHEN (cake) or "WE" for WECKER (alarm clock) are sign onsets with a very brief movement until the hands are in the correct position (*location)* of the intended sign (see section "Stimuli").

and the access to language input in the two populations (see e.g., Mayberry et al., 2011; Miller and Clark, 2011; Trezek et al., 2011). As a result, the control group was significantly younger than the group of native signers [native signers: $M$ = 10.7 years; $SD$ = 18 months; controls: $M$ = 8.8, $SD$ = 10 months; $t(26) = 4.16$, $p < 0.001$, Cohen's $d = 1.57$]. The two groups did not differ in non-verbal cognitive abilities [native signers: $M$ = 68.1, $SD$ = 25.9; controls: $M$ = 62.8, $SD$ = 27.1; $t(26) = -0.53$, $p = 0.603$, Cohen's $d = 0.20$]. Raven's Colored Progressive Matrices (Raven, 1936) were used as a measure of non-verbal cognitive ability. Percentile scores in relation to norms for German children are reported (Bulheller and Häcker, 2002).

## Stimuli

We used 80 concrete common nouns (see **Supplementary Material**), selected to be known to young children. As no lexical developmental scale for the acquisition of DGS exists, we checked the nouns with the CDI-ASL (Anderson and Reilly, 2002) and CDI-BSL (Woolfe et al., 2010). While targets consisted of complete written words, primes consisted of onsets of signs/spoken words. Following work by Friedrich et al. (2009) and Schild et al. (2011), spoken word onsets consisted of the first syllable of a respective target word. We created the spoken word onsets (fragments) by filming a hearing male actor speaking the complete words in front of a blue screen. Spoken fragments were created by editing each word after the first syllable. The sign stimuli were created by filming a female deaf native signer of DGS while she produced each noun in DGS in front of a blue screen. The signer was a professional employee of a sign language movie company.

As no grading system exists which would have allowed us to determine the point of uniqueness for DGS signs, we created the sign fragments by taking into account theories on sign phonology. Hereby, the parameter *location* is proposed to be equivalent to a syllable onset and *movement* and *location* properties serve as the skeletal structure for syllable-like units (for a more differentiated analysis of syllables in signs see Sandler, 1989; Brentari, 1998). The combination of movement and location has been shown to result in phonological effects on lexical retrieval which are similar across language modalities (Gutierrez et al., 2012a,b). Taking this as the basis for the production of the sign fragments, a deaf native signer cut each complete sign video at that point in time, when the hands were in the correct position in terms of *location*. Since sign phonological segments are expressed simultaneously, all sign fragments presented the correct *handshape* and a very brief *movement* ($M$ = 52.94 ms). Sign fragments ($M$ = 1418 ms, $SD$ = 108) were on average longer in duration than spoken fragments ($M$ = 1050 ms, $SD$ = 19).

In order to determine if these fragments were ambiguous sign onsets, we presented them to two deaf native and two deaf near-native signing adults whom we asked to complete each sign fragment as rapidly as possible. Out of 80 sign fragments, 43 resulted in the production of the intended complete sign by all participants ("unambiguous sign word onsets"). In contrast, the remaining 37 sign fragments received at least one different completion than the target sign it was created from ("ambiguous sign word onsets," marked by an asterisk in the **Supplementary Material**). Because we needed all trials in the ERP experiment and were limited in the choice of signs due to other criteria (e.g., that they were concrete nouns, known by young children) we decided to include all trials in the ERP analyses. However, for the reaction times, we additionally analyzed the responses for ambiguous vs. unambiguous word onsets separately (see section "Results").

For each participant, half the concrete nouns (i.e., 40) were used as targets in the Overlapping condition, and the other half were used as targets in the Unrelated condition. Allocation of targets to condition was counterbalanced across participants in both groups. The same primes were used to precede targets in both of these conditions. For example, a participant was presented with the prime followed by the target in the Overlapping condition (e.g., KU/"ku" – *Kuchen* [Engl. cake]) in one block and that same prime followed by the target for the Unrelated condition (e.g., KU/"ku" – *Wecker* [Engl. alarm clock]) in a different block. Additionally, 20 trials with pseudowords were presented for the lexical decision task. Pseudowords were created that differ only in the last one or two letters from the words. In 10 of those trials the prime and pseudoword showed overlap (e.g., AU/"au," *Aune* [pseudoword derived from Auto, Engl. car]); in the remaining 10 trials, the prime and the pseudoword were unrelated (e.g., prime for HUNG/"hung," *Namel* [pseudoword derived from Name, Engl. name]).

## Procedure

All participants were tested individually, in a quiet room in their school (native signers) or at the university (controls). After completing the reading and non-verbal cognitive ability tests, the EEG recording cap was fitted and the child was seated behind a computer.

Presentation® software (Neurobehavioral Systems, Inc., Berkeley, CA, United States)[2] was used to control stimulus presentation and record behavioral responses. All visual stimuli were presented on a computer screen placed approximately 40 cm in front of the participant, with videos of sign and spoken stimuli being presented at natural speed, and at a size of 21.4 cm by 17.1 cm, on a black background showing the face and torso of the speaker. Written stimuli were in white capital letters (font: Courier, font size: 41) on a black background. Auditory stimuli were presented to controls through speakers positioned directly to the right and the left of the computer screen.

Each trial began with the presentation of the fixation picture for 1,000 ms at the center of the screen, which participants were asked to fixate on whenever it appeared. The prime was presented, followed by a blank screen for 450 ms, before the target was presented. Subsequently, participants were asked to press the space bar only if they believed the target was a possible written word in German. A response was followed by a feedback stimulus (2,000 ms in duration) consisting of a smiley for correct and a picture of a ghost for incorrect responses. The next trial started after a 1,500 ms inter-trial interval (from response onset) during which the screen was blank. If participants did not

[2]www.neurobs.com

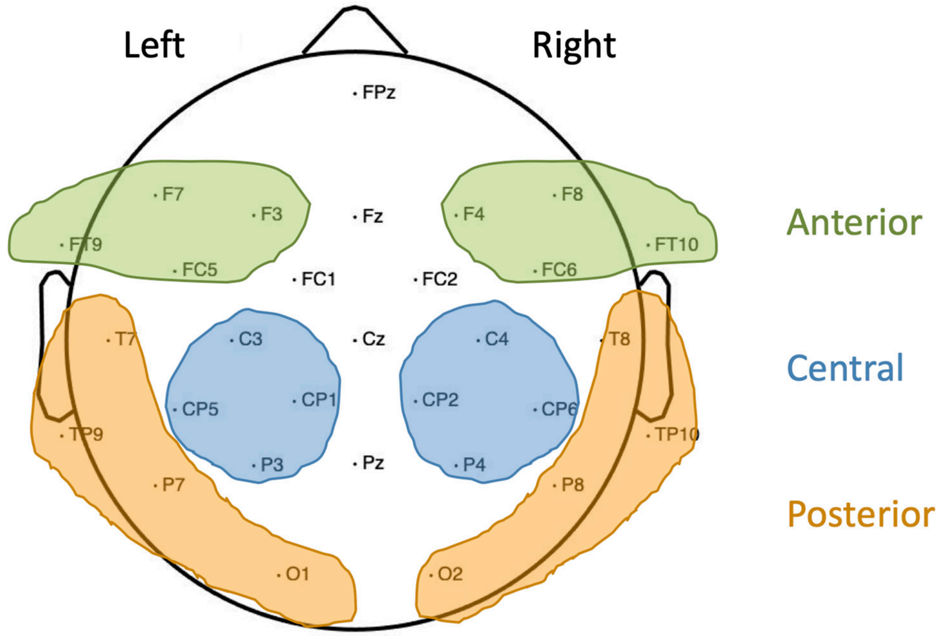


**FIGURE 2 |** Overview of electrodes used and regions of interest formed. For the P350, left and right anterior (shaded green) and posterior (shaded yellow) regions were used. For the N400, left and right central regions (shaded blue) were used.

respond within 5,000 ms, the task continued with the inter-trial interval regardless.

Trials were presented in one of two pseudo-random orders, and in blocks of 10 with short breaks in between. A set of 10 practice trials preceded the experimental blocks. Trial order and response hand were counterbalanced across participants in both groups. The total duration of the experiment was about 60 min (including breaks).

## Event Related Potential Recordings and Analysis

The continuous electroencephalogram (EEG; 500 Hz/22 bit sampling rate, 0.01–100 Hz bandpass) was recorded from 30 Ag/AgCl active electrodes (Brain Products) mounted into an elastic cap (Easycap) according to the 10–20 system. Additionally, electrodes F9 and F10 (positioned close to the outer canthi of the left and right eye) were used to monitor horizontal eye movements, while two further electrodes were attached below the eyes to record vertical eye movements, all referenced to the nose. A left frontal scalp electrode (AF3) served as ground. Off-line analysis was performed using BESA-Research software (MEGIS Software GmbH; Version 5.3): the EEG was re-referenced to an average reference, eye artifacts were corrected using surrogate Multiple Source Eye Correction by Berg and Scherg (1994), and noisy trials were manually excluded. If an electrode was noisy throughout a substantial part of the recording, this electrode was interpolated. In controls, for two children no electrodes were interpolated, for three children one electrode was interpolated, for seven children two electrodes were interpolated and for another two children, three electrodes were interpolated. In native signers, for eight children no electrodes were interpolated, for three children one electrode was interpolated and in another three children two electrodes were interpolated. A minimum of 22 artifact-free trials was included in each condition per child. Controls ($M = 31.11$, $SD = 5.05$) did not differ from native signers ($M = 32.21$, $SD = 3.30$) in the average number of artifact-free trials included per condition, $t(26) = 0.336$, $p = 0.74$, $d = 0.26$. Event-related potentials (ERPs) were computed for the target words with correct responses, starting from the beginning of the presentation of the written word up to 1,000 ms post-stimulus onset. The ERPs were baseline corrected to a 200 ms pre-stimulus period. The dependent variable for the ERPs was the mean amplitude for each participant in the Overlapping and the Unrelated condition across regions of interest and time windows informed by previous work (Friedrich et al., 2004a,b, 2013; Friedrich, 2005; Schild et al., 2011). For the P350, regions of interest were: left anterior (F7, F3, FT9, and FC5), right anterior (F4, F8, FC6, and F10), left posterior (T7, TP9, P7, and O1) and right posterior (T8, TP10, P8, and O2). For the N400, regions of interest were left central (C3, CP5, CP1, and P3) and right central (C4, CP2, CP6, and P4). Regions of interest are illustrated in **Figure 2**. Time windows for both the P350 and the N400 were 200–400 and 400–600 ms post-stimulus onset.

# RESULTS

## Behavioral Responses

In the lexical decision task, both groups were highly accurate in identifying words (percentage button presses in response to word targets), but native signers ($Mdn = 97.5\%$) were slightly less

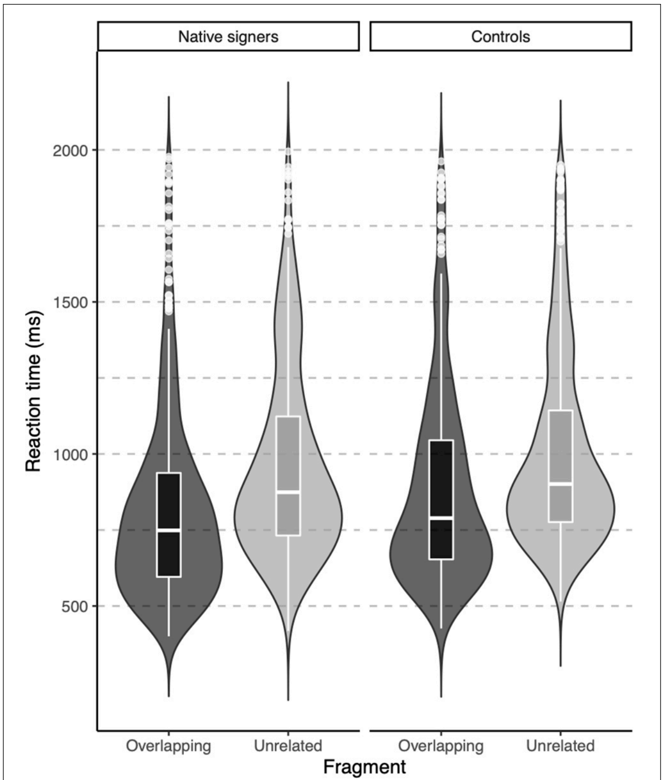


**FIGURE 3 |** Violin-boxplots depicting reaction times (in ms) for correct responses for Native signers (left) and Controls (right) for Overlapping (dark gray) and Unrelated (light gray) fragments.

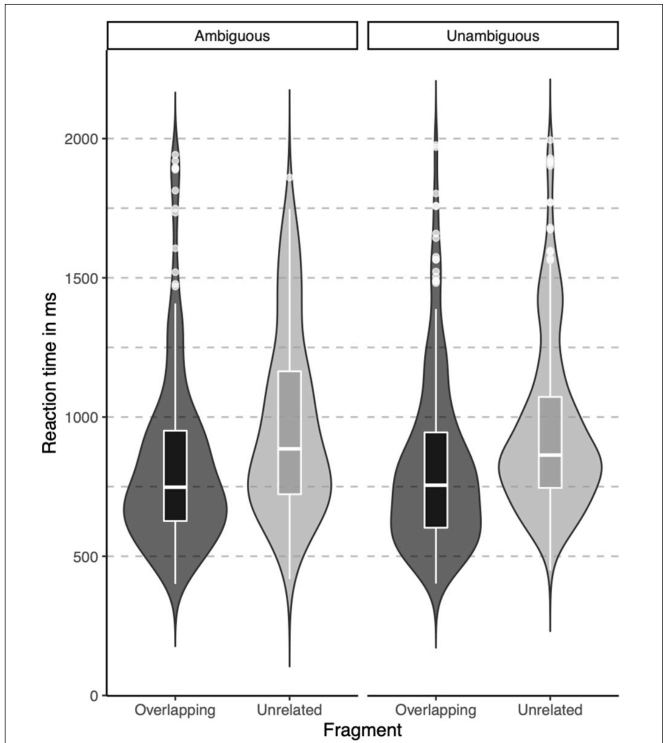


**FIGURE 4 |** Violin-boxplots depicting reaction times (in ms) for correct responses in Native signers only, for Ambiguous (left) and Unambiguous (right) fragments.

accurate than controls (*Mdn* = 100%), *U* = 46, *p* = 0.012. The native signers additionally more often identified pseudowords as words (percentage button presses in response to pseudowords; Native signers: *Mdn* = 35%, Controls: *Mdn* = 17.5%, *U* = 116, *p* = 0.042). Reaction times were only analyzed for correct responses to word targets. In **Figure 3**, violin-boxplots depict reaction times across groups and word onsets. As the reaction times showed considerable positive skew, values were log-transformed (using the natural logarithm) before we conducted an ANOVA with Group (Native signers vs. Controls) as a between-subject factor and Word Onset (Overlapping vs. Unrelated) as a within-subject factor. The effect of Group was not significant [$F(1,26) = 1.42$, $p = 0.244$], neither was the interaction with Group [$F(1,26) = 1.49$, $p = 0.233$]. Crucially, the main effect of Word Onset was significant [$F(1,26) = 107.27$, $p < 0.001$]. Both native signers (Overlapping: *M* = 817 ms, *SD* = 311 ms; Unrelated: *M* = 962, *SD* = 314) and controls (Overlapping: *M* = 888 ms, *SD* = 325 ms; Unrelated: *M* = 1002, *SD* = 314) were faster to respond when prime and target overlapped than when they were unrelated. In native signers, an additional ANOVA with Word Onset (Overlapping vs. Unrelated) and Predictability (Ambiguous vs. Unambiguous) as within-subject factors resulted in a significant main effect of Word Onset [$F(1,13) = 43.53$, $p < 0.001$]. Neither the main effect of Predictability $F(1,13) = 0.16$, $p = 0.700$, nor the interaction with Predictability $F(1,13) = 0.00$, $p = 0.950$ was significant. Native signers were faster to respond when prime and target overlapped than when they were unrelated, both for ambiguous word onsets (Overlapping: *M* = 829 ms, *SD* = 314 ms; Unrelated: *M* = 971, *SD* = 326) and unambiguous word onsets (Overlapping: *M* = 823 ms, *SD* = 308 ms; Unrelated: *M* = 956, *SD* = 307; see **Figure 4**).

## Event-Related Potentials

Grand average waveforms across word onsets (Overlapping vs. Unrelated) as well as difference waves (Unrelated – Overlapping) for each of the regions of interest (Anterior, Central and Posterior) and hemispheres (Left vs. Right) in both groups (Controls vs. Native signers) are presented in **Figure 5**. **Figure 6** shows topographical voltage maps of the difference waves across the 200–400 ms and 400–600 ms time windows for both groups. A posterior positivity, which we relate to the P350 effect, was visible in both groups. This effect was left-lateralized in controls, whereas it was bilaterally distributed in native signers. At central regions, a bilateral negativity, which we relate to the N400, was evident in both groups. Central tendencies and distributions of mean amplitudes across conditions and groups for the left and right hemispheric regions of interest are presented in **Figures 7**, **8**, for the P350/positivity and **Figures 9**, **10** for the N400/negativity.

For the P350 effect, a repeated-measures ANOVA with Word Onset (Overlapping vs. Unrelated), Region (Anterior vs. Posterior) and Hemisphere (Left vs. Right) as within-subject factors and Group (Controls vs. Native signers) as a between-subject factor was separately conducted for the lateral regions of interest for each time window (200–400 and 400–600 ms). For the N400 effect, a repeated-measures ANOVA with Condition (Overlapping vs. Unrelated) and Hemisphere (Left vs. Right) as within-subject factors and Group (Controls vs. Native signers) as a between-subject factor was conducted for the central regions of interest, for each time window (200–400 and 400–600 ms) separately.

In the 200–400 ms time window, regions of interest for the P350 effect revealed a significant four-way interaction of Condition × Hemisphere × Region × Group [$F(1,26) = 8.41$, $p = 0.008$], which we followed up by separate repeated-measures ANOVAs per region. For anterior regions of interest, no significant main effects of Condition, Hemisphere or Group nor any significant interactions between factors were found (all $p > 0.29$). For posterior regions of interest, significant main effects of Condition [$F(1,26) = 38.06$, $p < 0.001$] and Hemisphere [$F(1,26) = 6.68$, $p = 0.016$] were modulated by a significant Condition × Hemisphere interaction [$F(1,26) = 5.10$, $p = 0.033$]. *Post hoc* comparisons with Tukey's correction to account for multiple comparisons showed that mean amplitude in the 200–400 ms time window was more positive in the Unrelated condition compared to the Overlapping condition in the left posterior region [$M = -3.01$, $SE = 0.50$, $t(51.9) = -6.02$, $p < 0.001$] as well as in the right posterior region [$M = -1.45$, $SE = 0.50$, $t(51.9) = -2.90$, $p = 0.027$]. The main effect of Group was not significant [$F(1,26) = 0.28$, $p = 0.60$]; nor were any of the interactions with Group (all $p > 0.08$; for full results see **Supplementary Tables 1A–D**). Regions of interest for the N400 revealed a main effect of Condition [$F(1,26) = 21.40$, $p < 0.001$] only, with more negative amplitudes in the Unrelated condition than in the Overlapping condition. No other effects or interactions were significant (all $p > 0.06$, see **Supplementary Tables 3**, **4** for full results).

In the 400–600 ms time window, regions of interest for the P350 effect revealed a significant four-way interaction of Condition × Hemisphere × Region × Group [$F(1,26) = 9.42$, $p = 0.005$] which we followed up by separate repeated-measures ANOVAs per region. For anterior regions of interest, no significant main effects of Condition, Hemisphere or Group nor any significant interactions between factors were found (all $p > 0.37$). For posterior regions of interest, significant main effects of Condition [$F(1,26) = 7.17$, $p = 0.013$] and Hemisphere [$F(1,26) = 6.13$, $p = 0.020$] were modulated by a significant Condition × Hemisphere × Group interaction [$F(1,26) = 5.74$, $p = 0.024$]. The main effect of Group was not significant [$F(1,26) = 0.90$, $p = 0.35$], nor were other interactions with Group (all $p > 0.07$). *Post hoc* comparisons with Tukey's correction to account for multiple comparisons showed that mean amplitude in the 400–600 ms time window was more positive in the Unrelated condition compared to the Overlapping condition in the right posterior region in Native signers only [$M = -3.20$, $SE = 0.94$, $t(45.8) = -3.39$, $p = 0.028$; all other $p > 0.54$; for full results see **Supplementary Tables 2A–D**]. Regions of interest for the N400 revealed a main effect of Condition [$F(1,26) = 20.00$, $p < 0.001$] only, with more negative amplitudes in the Unrelated condition than in the Overlapping condition (all $p > 0.27$, see **Supplementary Tables 3**, **4** for full results).

## DISCUSSION

The main aim of the present study was to investigate whether and when during online processing beginning readers link signed language (deaf participants) or spoken language (hearing participants) to written word recognition. We tested two groups of children: congenitally deaf (native signing) and hearing beginning readers, who were matched on reading skill. Our behavioral results showed that both groups of children matched word onsets (signed or spoken) and written target words. Signed and spoken onsets facilitated lexical decisions to corresponding written words. ERPs were informative regarding aspects of processing that were involved when deaf and hearing children link their native language to reading. In both groups, rapid priming effects emerged as early as 200 ms after the onset of the written target word. That is, deaf and hearing beginning readers appeared to have used incremental processing in their native language for written word processing as rapidly as hearing adults do (see Friedrich et al., 2004a,b, 2008, 2013; Friedrich, 2005). Moreover, we found similar ERP deflections in onset priming in signing and hearing children and these ERP deflections resemble those in hearing adults. Together, our results suggest that the links attested in previous studies between sign language proficiency and reading in deaf readers (Padden and Ramsey, 1998; Chamberlain and Mayberry, 2008) might – at least in part – be mediated by implicit associations between representations of signs and written words that are automatically accessed already by beginning readers.

Facilitated lexical decision responses for targets which were preceded by a related word onset demonstrate that children link spoken language processing (hearing children) as well as sign language processing (deaf children) to reading. For hearing children, intimate links between spoken and written language are well established (for review see Goswami and Bryant, 2016). At the behavioral level, spoken-written priming of phonologically related words has been formerly observed for 8–10-year-olds (Clahsen and Fleischhauer, 2014; Quémart et al., 2018). For signing children, the present behavioral results are in line with findings showing links between sign language processing and reading in signing deaf adults (see Ormel and Giezen, 2014; Giezen and Emmorey, 2016 for reviews) and signing deaf children (Ormel et al., 2012; Villwock et al., 2021). However, response latencies reflect only the outcome of complex recognition and decision processes and do not allow disentangling whether facilitation reflects early, rather automatic, or later, rather decision related aspects of processing (for further discussion see Friedrich et al., 2013; Schild and Friedrich, 2018). In that respect, our neurocognitive data strengthen those claims. Moreover, they expand them and add more detailed information to those research questions.

Across both groups of children, ERP effects related to prime-target overlap manifested first in a time window ranging from 200 and 400 ms after target word onset. At lateral electrode

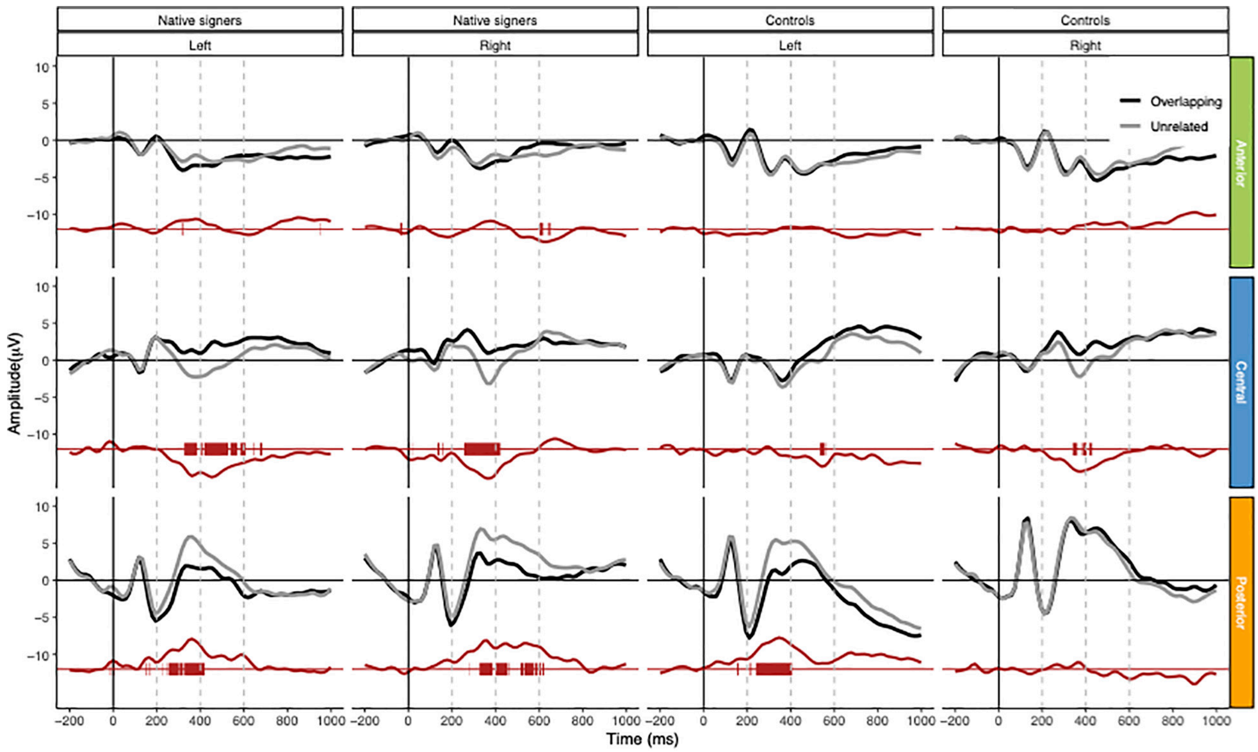


**FIGURE 5 |** Grand average waveforms for Native signers (left two columns) and Controls (right two columns) for the Overlapping (black line) and Unrelated (gray line) fragments across regions of interest (Anterior, Central, Posterior × Left, Right). In red, the difference wave (Unrelated – Overlapping) as well as an indication of a significant difference from zero (point-by-point; $p < 0.01$) for the difference waves. Vertical dashed gray lines indicate measurement windows.

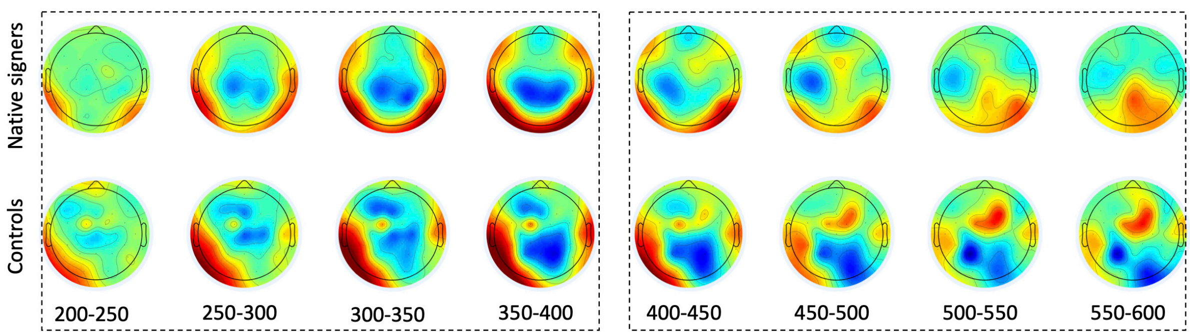


**FIGURE 6 |** Topographical voltage maps of the difference waves (Unrelated – Overlapping) for Native signers (upper panels) and Controls (lower panels) between 200 and 600 ms post-stimulus in 50 ms increments. Dashed boxes indicate time windows used for measurement. Green indicates zero, colors toward dark red indicate a positive difference, colors toward dark blue indicate a negative difference. Nose is at the top.

leads, prime-target overlap elicited more positive amplitudes (the P350 effect), whereas, at central electrodes, prime-target overlap elicited more negative amplitudes (the N400 effect) compared to unrelated pairs, respectively. This is in line with P350 and N400 effects previously reported for spoken - written word onset priming with hearing adults (Friedrich et al., 2004a,b, 2008, 2013; Friedrich, 2005). In contrast to ERP effects found for spoken-written word onset priming in hearing adults, P350 difference topographies in hearing and signing children were more pronounced for posterior than for anterior electrode leads. Thus, topographies of P350 effects for written target words appear to follow a posterior to anterior gradient from middle childhood to adulthood. This is somewhat remarkable as spoken word onset priming elicited comparable P350 difference topographies with (left-)anterior distribution of the effect in hearing adults (e.g., Friedrich et al., 2009; Schild et al., 2014; Schild and Friedrich, 2018) and in hearing children (preschoolers and first graders; Schild et al., 2011, Schild et al., 2014b). That is, there was no posterior to anterior gradient of P350 effects for spoken targets during development. We

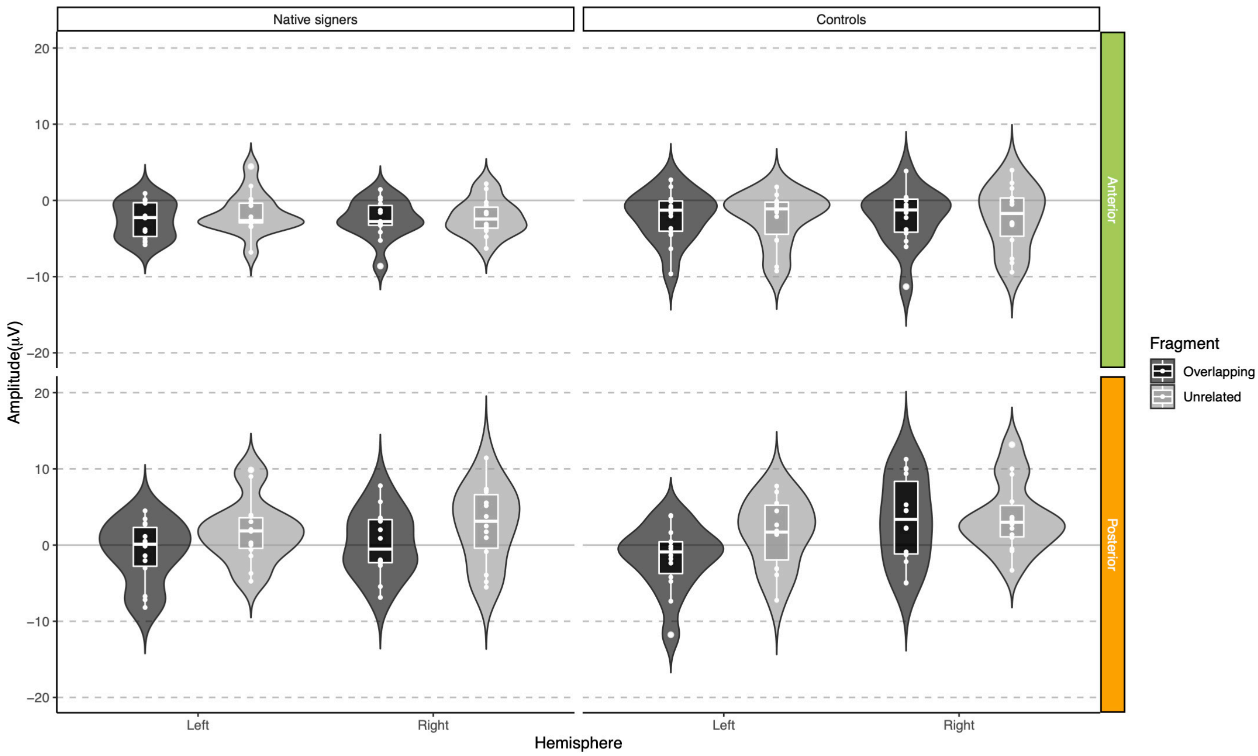


**FIGURE 7 |** Violin-boxplots depicting mean amplitude for the P350/positivity in the 200–400 ms time window for Native signers (left) and Controls (right) for the Unrelated (light gray) and Overlapping (dark gray) fragments across regions of interest.

might conclude that the neural processing of written words, as tapped by spoken-written word onset priming, undergoes more restructuring during development from middle childhood to adulthood than the neural processing of spoken words does. Nevertheless, we have to consider that we presented video clips of the speakers in the present study, while we presented unimodal spoken materials in all previous studies with children and adults.

In particular the earlier time window of ERP differences between related and unrelated pairs is associated with lexical access in written word recognition in hearing adults (e.g., Grainger et al., 2006; Holcomb and Grainger, 2006, 2007) and in signing adults (for signing readers see: Gutierrez-Sigut et al., 2017). Therefore, we conclude that hearing children are linking incremental processing in the spoken domain to written word processing as early as hearing adults do. Similarly, signing children are linking incremental processing of signs to written word processing as early as adult signers do. In particular, our results show that beginning readers are sensitive to the outcome of some sort of matching between representations of different modalities (spoken/signed and written) and target word processing is affected by mismatches. Note that this is the first study providing neurocognitive data with high temporal resolution demonstrating that deaf signing children rapidly exploit sign word onsets to facilitate written word identification. Our results point to the conclusion that native signing children are activating written word representations on the basis of sign word onsets similar to hearing children activating written word representations on the basis of spoken word onsets.

How could incrementally processed signs modulate the processing of written words? One possibility is that mouthings, which are relatively common in DGS, might provide some direct form hints between signs and written word representations. Mouthings relate to the phonology of spoken language as they are speech-derived mouth actions accompanying manual signs (Boyes-Braem and Sutton-Spence, 2001; Brentari, 2011). There might be some grapheme-mouthing correspondence between DGS and written German, which deaf native signers can use similarly to grapheme-phoneme correspondence that hearing readers use. Studies focusing on co-active mouth patterns in deaf readers report some reliable mapping between orthography and mouthing (Vinson et al., 2010; Giustolisi et al., 2017). This is consistent with an fMRI study demonstrating that mouthings accompanied by signs generated activations similar to speech reading, while mouth patterns unrelated to spoken language (called "mouth gestures") generated activations similar to manual signs without mouth movements (Capek et al., 2008). Indeed, we found naturally produced mouth patterns in the sign word onsets that we presented (see video examples in the **Supplementary Material**). Therefore, our results might further inform the ongoing debate on whether mouthings and manual components have shared lexical representations or whether mouthings occur incidentally by simultaneous code mixing and blending (see Sutton-Spence, 1999; Boyes-Braem and Sutton-Spence, 2001;

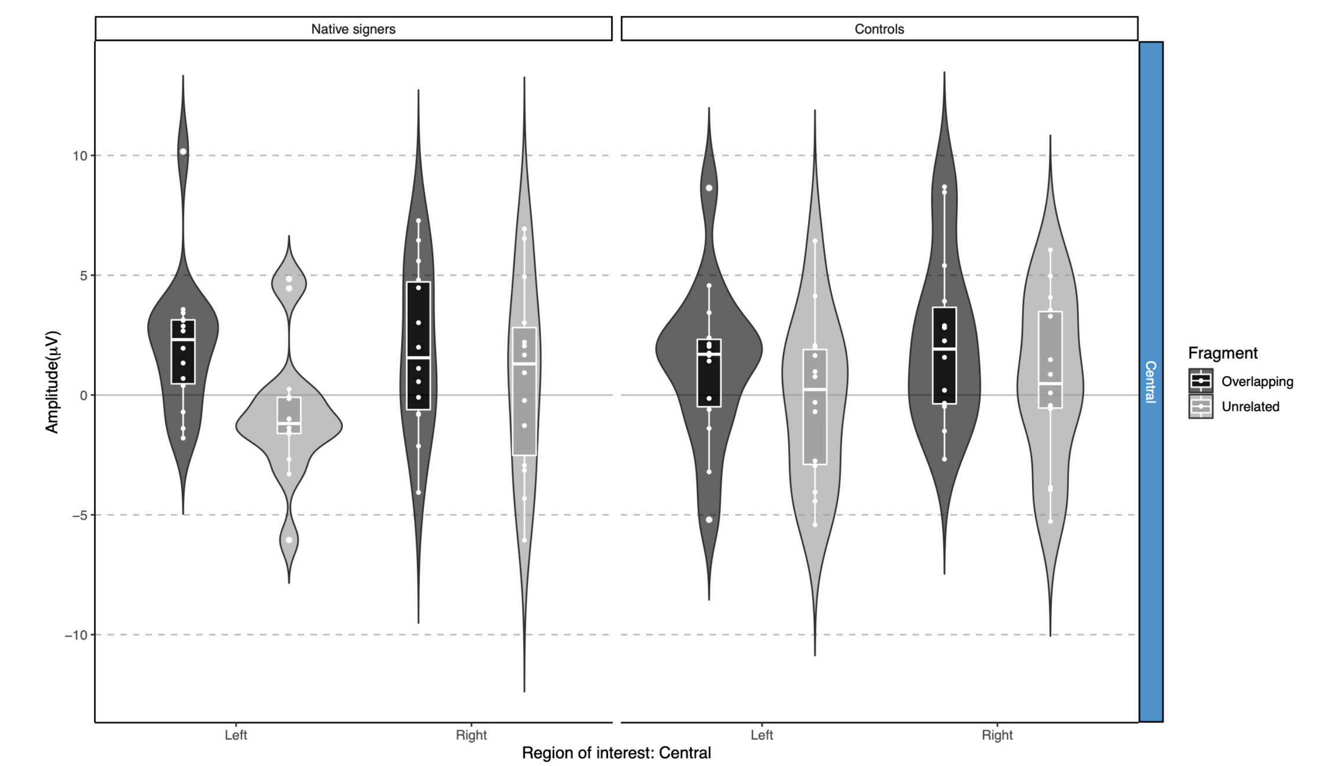


**FIGURE 8 |** Violin-boxplots depicting mean amplitude for the P350/positivity in the 400–600 ms time window for Native signers (left) and Controls (right) for the Unrelated (light gray) and Overlapping (dark gray) fragments across regions of interest.

Sutton-Spence and Day, 2001; Emmorey et al., 2005; Johnston and Schembri, 2007; Nadolske and Rosenstock, 2007; Donati and Branchini, 2013).

In particular the early onset of effects in the ERPs obtained for both groups of beginning readers might confirm the assumption that lexical access is neither selective to the modality (sign, spoken, or written) nor to the language (sign language or written language) of the input that the system receives (Morford et al., 2011, 2019). Non-selective lexical access is well established in research with hearing bilinguals (Spivey and Marian, 1999; Lagrou et al., 2011; for review see Kroll et al., 2015). In previous spoken-written word onset priming studies with hearing adults, we already related the P350 effect to modality-independent lexical access (Friedrich et al., 2004a, 2013; Friedrich, 2005). The present results suggest that the ERP effects obtained in word onset priming might be language non-selective as well. With respect to native signing beginning readers, we might conclude that they can facilitate lexical access to written word recognition via an implicit language non-selective linguistic pathway (for a similar conclusion drawn from priming data see Villwock et al., 2021). Hence, reading proficiency might well be modulated by sign language proficiency (McQuarrie and Abbott, 2013; Corina et al., 2014; Holmer et al., 2016). Moreover, deaf readers might even uniquely benefit from language non-selective lexical access during reading since there is typically less competition between phonological and orthographical patterns between signs and words compared to competition between co-activated spoken words and respective written words in hearing individuals (for further discussion see Morford et al., 2019).

P350 effects elicited in signing and hearing beginning readers were similar in their timing, but differed in the lateralization of the posteriorly distributed ERP differences. Similar to previous spoken-written priming studies with adults (Friedrich et al., 2004a,b, 2008, 2009), hearing children in the present study showed a left-lateralized P350 effect. In contrast, deaf native signing children showed a bilateral distribution of the P350 effect. Given the inverse problem in ERP research, topographic ERP effects have to be interpreted with caution. However, the different topography of P350 effects in hearing and deaf beginning readers that we obtained here is consistent with topographic differences of ERP effects formerly shown for deaf and reading adults (Neville et al., 1982; Emmorey et al., 2017; Sehyr et al., 2020). For example, for word reading, individual reading ability was associated with a larger N170 over right-hemispheric occipital sites for deaf readers. By contrast, reading ability was associated with a smaller N170 over the right hemisphere for hearing readers (Emmorey et al., 2017; Sehyr et al., 2020). These ERP findings converge with fMRI evidence for more bilaterally distributed networks that deaf signers recruit for reading (compared to hearing readers; Emmorey et al., 2013). In light of these ERP and fMRI studies with deaf adult readers, the bilateral P350 response in deaf native signing children (compared to the left-lateralized response in reading matched hearing children) might integrate into the assumption that deaf signers recruit the right hemisphere

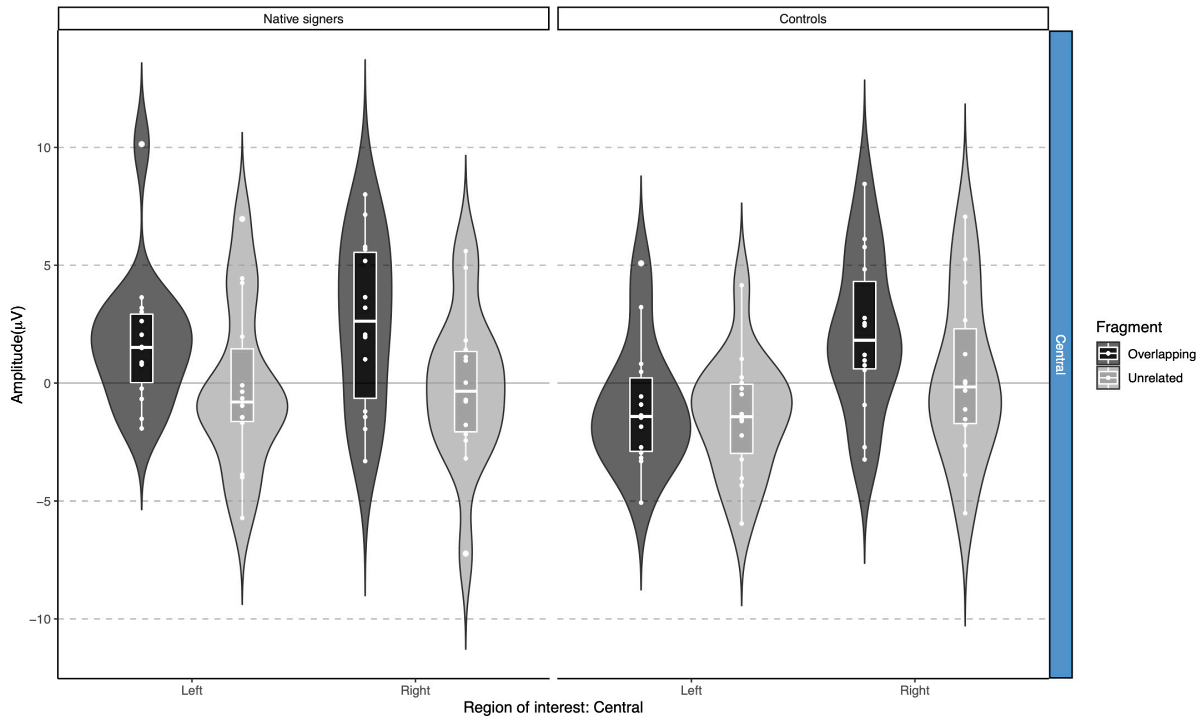


**FIGURE 9 |** Violin-boxplots depicting mean amplitude for the N400/negativity in the 200–400 ms time window for Native signers (left) and Controls (right) for the Unrelated (light gray) and Overlapping (dark gray) fragments across regions of interest.

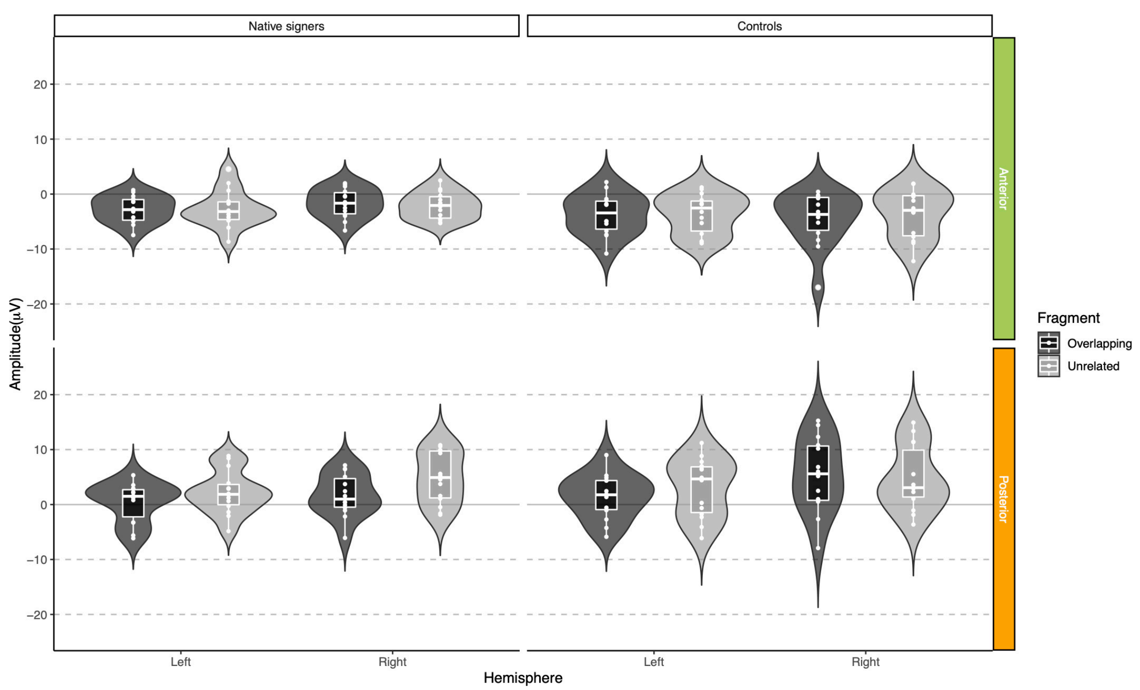


**FIGURE 10 |** Violin-boxplots depicting mean amplitude for the N400/negativity in the 400–600 ms time window for Native signers (left) and Controls (right) for the Unrelated (light gray) and Overlapping (dark gray) fragments across regions of interest.

for processing visual word forms to a greater extent than hearing readers do (see also Emmorey and Lee, 2021).

Following the P350 effect and the N400 effect in the ERPs, there was evidence for some later ERP differences between overlapping and unrelated prime-target pairs (see **Figure 5**). Formerly, we discussed extended positive-going ERP effects for related spoken word targets as being evidence for long-lasting facilitation of respective candidate words (see Friedrich et al., 2013). However, the present design does not allow us to compare these extended ERP effects to the processing of more or less appropriate related candidate words as we did in the former study with matching and partially mismatching spoken target words. In addition to extended facilitation, late ERP effects might also reflect strategic effects associated with the lexical decision responses, which ranged between approximately 820 and 1,000 ms after target word onset (see also Friedrich et al., 2013). Future research with systematically varied prime-target overlap has to further investigate the functional role of these late ERP effects, which appear to be more pronounced in the beginning signing readers than in the beginning hearing readers (see **Figure 5**).

With regard to different sub-processes that might be reflected in the P350 effect, in the N400 effect and in the reaction times (for further discussion see Friedrich et al., 2013; Schild and Friedrich, 2018), word onset priming might provide a promising tool to further investigate aspects of processing that might have contributed to diverging ERP effects obtained in previous sign priming studies. For example, signed prime-target pairs overlapping in sign units have been found to either cause behavioral facilitation (Dye and Shih, 2006), no effect (Mayberry and Witcher, 2005), or even inhibition (Corina and Hildebrandt, 2002; Carreiras et al., 2008; compared to unrelated prime-target pairs, respectively). In parallel, some ERP studies have revealed either a reduced N400 when signed primes and targets overlapped (compared to completely unrelated prime-target pairs; for ASL: Meade et al., 2018; Hosemann et al., 2020), while others obtained an enhanced N400 for overlap (compared to completely unrelated prime-target pairs; Baus and Carreiras, 2012; Gutierrez et al., 2012a). This might suggest that different sign parameters differently affect different aspects of processing. A recent eye tracking study on Cantonese reading with Hong Kong Sign Language systematically varying different sign parameters also pointed in that direction (Thierfelder et al., 2020). One might suggest that the parallel activation of multiple memory representations for words (presumably reflected in the P350 effect) and the selection of the most promising candidate among them (presumably reflected in the N400 effect and in the lexical decision latencies) are differently sensitive to different units of sign language.

## CONCLUSION

The present study indicates that deaf beginning readers engage rapid sign language co-activation during visual word recognition. Sign onset primes modulated ERP responses of following written target words with lexical overlap to the primes. ERP effects started 200 ms after target word onset. This suggests that deaf beginning readers implicitly link signs to written word recognition. In addition, consecutive selection mechanisms underlying the behavioral responses appeared to be facilitated for matching targets. Our results demonstrate co-activation from DGS as a native language to written German as a second language in deaf signing beginning readers. ERPs recorded in signing individuals might be a promising tool to disentangle which incremental and lexical processes in written word recognition link to which aspects of processing in the signed domain.

## DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Ethikkommission der Deutschen Gesellschaft für Psychologie. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

## AUTHOR CONTRIBUTIONS

BH-F: conceptualization, funding, supervision, investigation, writing – original draft, and writing – review and editing. MG: formal analysis, investigation, and writing – review and editing. BR: conceptualization, funding, supervision, and writing – review and editing. CF: conceptualization, funding, supervision, investigation, and writing – reviewing and editing. All authors contributed to the article and approved the submitted version.

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## SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2022.917700/full#supplementary-material

## REFERENCES


Allopenna, P. D., Magnuson, J. S., and Tanenhaus, M. K. (1998). Tracking the time course of spoken word recognition using eye movements: evidence for continuous mapping models. *J. Mem. Lang.* 38, 419–439. doi: 10.1006/jmla.1997.2558

Anderson, D., and Reilly, J. (2002). The MacArthur Communicative Development Inventory: normative data for American Sign Language. *J. Deaf Stud. Deaf Educ.* 7, 83–106. doi: 10.1093/deafed/7.2.83

Baus, C., and Carreiras, M. (2012). "Word processing," in *Language from a Biological Point of View: Current Issues in Biolinguistics*, eds C. Boeckx, M. C. Horno-Chéliz, and J. L. Mendívil-Giró (Cambridge: Scholars), 165–183.

Berg, P., and Scherg, M. (1994). A multiple source approach to the correction of eye artifacts. *Electroencephalogr. Clin. Neurophysiol.* 90, 229–241. doi: 10.1016/0013-4694(94)90094-9

Boyes-Braem, P., and Sutton-Spence, R. (2001). *The Hands are the Head of the Mouth: The Mouth as Articulator in Sign Languages*. Hamburg: Signum

Brentari, D. (1998). *Prosodic Model of Sign Language Phonology*. Cambridge: MIT Press

Brentari, D. (2011). "Sign language phonology," in *The Handbook of Phonological Theory*, 2 Edn, eds J. Goldsmith, J. Riggle, and A. C. L. Yu (Chichester: Blackwell Publishing), 691–721.

Bulheller, S., and Häcker, H. (2002). *Coloured Progressive Matrices (CPM)*. 3 ed, Frankfurt: Harcourt

Capek, C. M., Waters, D., Woll, B., MacSweeney, M., Brammer, M. J., McGuire, P. K., et al. (2008). Hand and mouth: cortical correlates of lexical processing in British Sign Language and speechreading English. *J. Cogn. Neurosci.* 20, 1220–1234. doi: 10.1162/jocn.2008.20084

Carreiras, M., Gutiérrez-Sigut, E., Baquero, S., and Corina, D. (2008). Lexical processing in Spanish Sign Language (LSE). *J. Mem. Lang.* 58, 100–122. doi: 10.1016/j.jml.2007.05.004

Chamberlain, C., and Mayberry, R. I. (2008). ASL syntactic and narrative comprehension in skilled and less skilled adults readers: bilingual-bimodal evidence for the linguistic basis of reading. *Appl. Psycholinguist.* 28, 537–549. doi: 10.1017/S014271640808017X

Clahsen, H., and Fleischhauer, E. (2014). Morphological priming in child German. *J. Child Lang.* 41, 1305–1333. doi: 10.1017/S0305000913000494

Clark, L. E., and Grosjean, F. (1982). Sign recognition processes in American Sign Language: the effect of context. *Lang. Speech* 25, 325–340.doi: 10.1177/002383098202500402

Corina, D. P., Hafer, S., and Welch, K. (2014). Phonological awareness for American Sign Language. *J. Deaf Stud. Deaf Educ.* 19, 530–545. doi: 10.1093/deafed/enu023

Corina, D. P., and Hildebrandt, U. (2002). "Psycholinguistic investigations of phonological structure in AmericanSign Language," in *Modality and Structure in Signed and Spoken Languages*, eds R. P. Meier, K. Cormier, and D. Quinto-Pozos (Cambridge: Cambridge University Press), 88–111.

Dahan, D., Magnuson, J. S., Tanenhaus, M. K., and Hogan, E. M. (2001). Subcategorical mismatches and the time course of lexical access: evidence for lexical competition. *Lang. Cogn. Proces.* 16, 507–534. doi: 10.1080/01690960143000074

Donati, C., and Branchini, C. (2013). "Challenging linearization: Simultaneous mixing in the production of bimodal," in *Challenges to Linearization*, eds I. Roberts and T. Biberauer (Berlin, Boston: De Gruyter Mouton), 93–128.

Dye, M. W. G., and Shih, S. (2006). "Phonological priming in British Sign Language," in *Laboratory Phonology*, eds L. Goldstein, D. H. Whalen, and T. Best (Berlin: Mouton de Gruyter), 243–263.

Emmorey, K., Borinstein, H., and Thompson, R. (2005). "Bimodal bilingualism: code-blending between spoken English and American Sign Language," in *ISB4: Proceedings of the 4th International Symposium on Bilingualism*, eds J. Cohen, K. T. McAlister, K. Rolstad, and J. MacSwan (Somerville, MA: Casadilla Press), 663–673.

Emmorey, K., and Corina, D. (1990). Lexical recognition in sign language: effects of phonetic structure and morphology. *Percept. Mot. Skills* 71, 1227–1252. doi: 10.2466/pms.1990.71.3f.1227

Emmorey, K., and Lee, B. (2021). The neurocognitive basis of skilled reading in prelingually and profoundly deaf adults. *Lang. Linguist. Compass* 15:e12407. doi: 10.1111/lnc3.12407

Emmorey, K., Midgley, K. J., Kohen, C. B., Sehyr, Z. S., and Holcomb, P. J. (2017). The N170 ERP component differs in laterality, distribution, and association with continuous reading measures for deaf and hearing readers. *Neuropsychologia* 106, 298–309. doi: 10.1016/j.neuropsychologia.2017.10.001

Emmorey, K., Weisberg, J., McCullough, S., and Petrich, J. A. F. (2013). Mapping the reading circuitry for skilled deaf readers: an fMRI study of semantic and phonological processing. *Brain Lang.* 126, 169–180. doi: 10.1016/j.bandl.2013.05.001

Ferrand, L., and Grainger, J. (1992). Phonology and orthography in visual word recognition: evidence from masked non-word priming. *Q. J. Exp. Psychol. A* 45, 353–372. doi: 10.1080/02724989208250619

Friedrich, C. K. (2005). Neurophysiological correlates of mismatch in lexical access. *BMC Neurosci.* 6:64. doi: 10.1186/1471-2202-6-64

Friedrich, C. K., Felder, V., Lahiri, A., and Eulitz, C. (2013). Activation of Words with Phonological Overlap. *Front. Psychol.* 4:556. doi: 10.3389/fpsyg.2013.00556

Friedrich, C. K., Kotz, S. A., Friederici, A. D., and Alter, K. (2004a). Pitch modulates lexical identification in spoken word recognition: eRP and behavioral evidence. *Cogn. Brain Res.* 20, 300–308. doi: 10.1016/j.cogbrainres.2004.03.007

Friedrich, C. K., Kotz, S. A., Friederici, A. D., and Gunter, T. C. (2004b). ERPs reflect lexical identification in word fragment priming. *J. Cogn. Neurosci.* 16, 541–552.

Friedrich, C. K., Lahiri, A., and Eulitz, C. (2008). Neurophysiological evidence for underspecified lexical representations: asymmetries with word initial variations. *J. Exp. Psychol. Hum. Percept. Perform.* 34, 1545–1559. doi: 10.1037/a0012481

Friedrich, C. K., Schild, U., and Röder, B. (2009). Electrophysiological indices of word fragment priming allow characterizing neural stages of speech recognition. *Biol. Psychol.* 80, 105–113. doi: 10.1016/j.biopsycho.2008.04.012

Giezen, M. R., and Emmorey, K. (2016). Language co-activation and lexical selection in bimodal bilinguals: evidence from picture-word interference. *Bilingualism* 19, 264–276. doi: 10.1017/s1366728915000097

Giustolisi, B., Mereghetti, E., and Cecchetto, C. (2017). Phonological blending or code mixing? Why mouthing is not a core component of sign language grammar. *Nat. Lang. Linguist. Theory* 35, 347–365. doi: 10.1007/s11049-016-9353-9

Goswami, U., and Bryant, P. (2016). *Phonological Skills and Learning to Read*. New York: Routledge

Grainger, J., Kiyonaga, K., and Holcomb, P. J. (2006). The time course of orthographic and phonological code activation. *Psychol. Sci.* 17, 1021–1026.

Grosjean, F. (1981). Sign and word recognition: a first comparison. *Sign Lang. Stud.* 32, 195–220.

Gutierrez, E., Müller, O., Baus, C., and Carreiras, M. (2012a). Electrophysiological evidence for phonological priming in Spanish Sign Language lexical access. *Neuropsychologia* 50, 1335–1346. doi: 10.1016/j.neuropsychologia.2012.02.018

Gutierrez, E., Williams, D., Grosvald, M., and Corina, D. (2012b). Lexical access in American Sign Language: an ERP investigation of effects of semantics and phonology. *Brain Res.* 1468, 63–83. doi: 10.1016/j.brainres.2012.04.029

Schild, U., Becker, A. B., and Friedrich, C. K. (2014b). Processing of syllable stress is functionally different from phoneme processing and does not profit from literacy acquisition. *Front. Psychol.* 5:530. doi: 10.3389/fpsyg.2014.00530

Gutierrez-Sigut, E., Vergara-Martínez, M., and Perea, M. (2017). Early use of phonological codes in deaf readers: an ERP study. *Neuropsychologia* 106, 261–279. doi: 10.1016/j.neuropsychologia.2017.10.006

Holcomb, P. J., Anderson, J., and Grainger, J. (2005). An electrophysiological study of cross-modal repetition priming. *Psychophysiology* 42, 493–507. doi: 10.1111/j.14698986.2005.00348.x

Holcomb, P. J., and Grainger, J. (2006). On the time course of visual word recognition: an event-related potential investigation using masked repetition priming. *J. Cogn. Neurosci.* 18, 1631–1643. doi: 10.1162/jocn.2006.18.10.1631

Holcomb, P. J., and Grainger, J. (2007). Exploring the temporal dynamics of visual word recognition in the masked repetition priming paradigm using event-related potentials. *Brain Res.* 1180, 39–58. doi: 10.1016/j.brainres.2007.06.110

Holmer, E., Heimann, M., and Rudner, M. (2016). Evidence of an association between sign language phonological awareness and word reading in deaf and hard-of-hearing children. *Res. Dev. Disabil.* 48, 145–159. doi: 10.1016/j.ridd.2015.10.008

Hosemann, J., Mani, N., Herrmann, A., Steinbach, M., and Altvater-Mackensen, N. (2020). Signs activate their written word translation in deaf adults: an ERP study on cross-modal co-activation in German Sign Language. *Glossa A J. Gen. Lingusit.* 5:57. doi: 10.5334/gjgl.1014

Johnston, T. A., and Schembri, A. (2007). *Australian Sign Language (Auslan): An Introduction to Sign Language Linguistics*. Cambridge: Cambridge University Press.

Kroll, J. F., Dussias, P. E., Bice, K., and Perrotti, L. (2015). Bilingualism, mind, and brain. *Annu. Rev. Linguist.* 1, 377–394. doi: 10.1146/annurev-linguist-030514-124937

Kubus, O., Villwock, A., Morford, J. P., and Rathmann, C. (2015). Word recognition in deaf readers: cross-language activation of German Sign Language and German. *Appl. Psycholinguist.* 36, 831–854. doi: 10.1017/S0142716413000520

Lagrou, E., Hartsuiker, R. J., and Duyck, W. (2011). Knowledge of a second language influences auditory word recognition in the native language. *J. Exp. Psychol. Learn. Mem. Cogn.* 37, 952–965. doi: 10.1037/a0023217

Lee, B., Meade, G., Midgley, K. J., Holcomb, P. J., and Emmorey, K. (2019). ERP Evidence for co-activation of English words during recognition of American Sign Language signs. *Brain Sci.* 9:148. doi: 10.3390/brainsci9060148

Lenhard, W., and Schneider, W. (2006). *ELFE 1-6: Ein Leseverständnistest für Erst- bis Sechstklässler*. Göttingen: Hogrefe.

Mayberry, R. I., del Giudice, A. A., and Lieberman, A. M. (2011). Reading achievement in relation to phonological coding and awareness in deaf readers: a meta-analysis. *J. Deaf Stud. Deaf Educ.* 16, 164–188. doi: 10.1093/deafed/enq049

Mayberry, R. I., and Witcher, P. (2005). *Age of Acquisition Effects on Lexical Access in ASL: Evidence for the Psychological Realitiy of Phonological Processing in Sign Language. Paper Presented at the 30th*. Boston: University conference on language development.

McQuarrie, L., and Abbott, M. (2013). Bilingual deaf students' phonological awareness in ASL and reading skills in English. *Sign Lang. Stud.* 14, 80–100. doi: 10.1353/sls.2013.0028

Meade, G., Lee, B., Midgley, K. J., Holcomb, P. J., and Emmorey, K. (2018). Phonological and semantic priming in American Sign Language: n300 and N400 effects. Language. *Cogn. Neurosci.* 33, 1092–1106. doi: 10.1080/23273798.2018.1446543

Meade, G., Midgley, K. J., Sehyr, Z., Holcomb, P. J., and Emmorey, K. (2017). Implicit co-activation of American Sign Language in deaf readers: an ERP study. *Brain Lang.* 170, 50–61. doi: 10.1016/j.bandl.2017.03.004

Miller, P. (2007). The role of spoken and sign languages in the retention of written words by prelingually deafened native signers. *J. Deaf Stud. Deaf Educ.* 12, 184–208. doi: 10.1093/deafed/enl031

Miller, P., and Clark, M. D. (2011). Phonemic awareness is not necessary to become a skilled deaf reader. *J. Dev. Phys. Disabil.* 23, 459. doi: 10.1007/s10882-011-9246-0

Morford, J. P., Kroll, J. F., Piñar, P., and Wilkinson, E. (2014). Bilingual word recognition in deaf and hearing signers: effects of proficiency and language dominance on cross-language activation. *Second Lang. Res.* 30, 251–271. doi: 10.1177/0267658313503467

Morford, J. P., Occhino, C., Zirnstein, M., Kroll, J. F., Wilkinson, E., and Piñar, P. (2019). What is the source of bilingual cross-language activation in deaf bilinguals? *J. Deaf Stud. Deaf Educ.* 24, 356–365. doi: 10.1093/deafed/enz024

Morford, J. P., Wilkinson, E., Villwock, A., Piñar, P., and Kroll, J. F. (2011). When deaf signers read English: do written words activate their sign translations? *Cognition* 118, 286–292. doi: 10.1016/j.cognition.2010.11.006

Nadolske, M. A., and Rosenstock, R. (2007). "Occurrence of mouthings in American Sign Language: A preliminary study," in *Visible Variation: Comparative Studies on Sign Language Structure*, eds P. M. Perniss, R. Pfau, and M. Steinbach (Berlin: De Gruyter Mouton), 35–62.

Neville, H. J., Kutas, M., and Schmidt, A. (1982). Event-related potential studies of cerebral specialization during reading: iI. Studies of congenitally deaf adults. *Brain Lang.* 16, 316–337. doi: 10.1016/0093-934X(82)90089-X

Ormel, E., and Giezen, M. R. (2014). "Bimodal bilingual cross-language interaction: Pieces of the puzzle," in *Bilingualism and Bilingual Deaf Education*, eds M. Marschark, G. Tang, and H. Knoors (New York: Oxford University Press), 75–101.

Ormel, E., Hermans, D., Knoors, H., and Verhoeven, L. (2009). The role of sign phonology and iconicity during sign processing: the case of deaf children. *J. Deaf Stud. Deaf Educ.* 14, 436–448. doi: 10.1093/deafed/enp021

Ormel, E., Hermans, D., Knoors, H., and Verhoeven, L. (2012). Cross-language effects in written word recognition: the case of bilingual deaf children. Bilingualism. *Lang. Cogn.* 15, 288–303. doi: 10.1017/S1366728911000319

Padden, C., and Ramsey, C. (1998). Reading ability in signing deaf children. *Top. Lang. Disord.* 18, 30–46. doi: 10.1097/00011363-199898000-00005

Papaspyrou, C., von Meyenn, A., Matthaei, M., and Herrmann, B. (2008). *Grammatik der Deutschen Gebärdensprache aus Der Sicht Gehörloser Fachleute*. Hamburg: Signum.

Pattamadilok, C., Chanoine, V., Pallier, C., Anton, J. L., Nazarian, B., Belin, P., et al. (2017). Automaticity of phonological and semantic processing during visual word recognition. *NeuroImage* 149, 244–255. doi: 10.1016/j.neuroimage.2017.02.003

Perfetti, C. A., and Sandak, R. (2000). Reading optimally builds on spoken language: implications for deaf readers. *J. Deaf Stud. Deaf Educ.* 5, 32–50. doi: 10.1093/deafed/5.1.32

Quandt, L. C., and Kubicek, E. (2018). Sensorimotor characteristics of sign translations modulate EEG when deaf signers read English. *Brain Lang.* 187, 9–17. doi: 10.1016/j.bandl.2018.10.001

Quémart, P., Gonnerman, L. M., Downing, J., and Deacon, S. H. (2018). The development of morphological representations in young readers: a cross-modal priming study. *Dev. Sci.* 21:e12607. doi: 10.1111/desc.12607

Raven, J. C. (1936). *Mental Tests Used in Genetic Studies: The Performance of Related Individuals on Tests Mainly Educative and Mainly Reproductive*, Ph.D thesis, United Kingdom, UK: King's College London

Reitsma, P. (1984). Sound priming in beginning readers. *Child Dev.* 55, 406–423. doi: 10.2307/1129952

Sandler, W. (1989). *Phonological Representation of the Sign: Linearity and Nonlinearity in American Sign Language*. Dordrecht: De Gruyter Mouton

Sandler, W., and Lillo-Martin, D. (2006). *Sign Language and Linguistic Universals*. Cambridge, UK: Cambridge University Press.

Sauval, K., Casalis, S., and Perre, L. (2017). Phonological contribution during visual word recognition in child readers. An intermodal priming study in Grades 3 and 5. *J. Res. Read.* 40, 158–169. doi: 10.1111/1467-9817.12070

Schild, U., Becker, A. B., and Friedrich, C. K. (2014). Phoneme-free prosodic representations are involved in pre-lexical and lexical neurobiological mechanisms underlying spoken word processing. *Brain Lang.* 136, 31–43. doi: 10.1016/j.bandl.2014.07.006

Schild, U., and Friedrich, C. K. (2018). What determines the speed of speech recognition? Evidence from congenitally blind adults. *Neuropsychologia* 112, 116–124. doi: 10.1016/j.neuropsychologia.2018.03.002

Schild, U., Röder, B., and Friedrich, C. K. (2011). Learning to read shapes the activation of neural lexical representations in the speech recognition pathway. *Dev. Cogn. Neurosci.* 1, 163–174. doi: 10.1016/j.dcn.2010.11.002

Sehyr, Z. S., Midgley, K. J., Holcomb, P. J., Emmorey, K., Plaut, D. C., and Behrmann, M. (2020). Unique N170 signatures to words and faces in deaf ASL signers reflect experience-specific adaptations during early visual processing. *Neuropsychologia* 141:107414. doi: 10.1016/j.neuropsychologia.2020.107414

Soto-Faraco, S., Sebastián-Gallés, N., and Cutler, A. (2001). Segmental and suprasegmental mismatch in lexical access. *J. Mem. Lang.* 45, 412–432. doi: 10.1006/jmla.2000.2783

Spinelli, E., Segui, J., and Radeau, M. (2001). Phonological priming in spoken word recognition with bisyllabic targets. *Lang. Cogn. Proces.* 16, 367–392. doi: 10.1080/01690960042000111

Spivey, M. J., and Marian, V. (1999). Cross-talk between native and second languages: partial activation of an irrelevant lexicon. *Psychol. Sci.* 10, 281–284. doi: 10.1111/1467-9280.00151

Sutton-Spence, R. (1999). The influence of English on British Sign Language. *Int. J. Biling.* 3, 363–394. doi: 10.1177/13670069990030040401

Sutton-Spence, R., and Day, L. (2001). "Mouthings and mouth gesture in British Sign Language (BSL)," in *The Hands are the Head of the Mouth: The Mouth as Articulator in Sign Languages*, eds P. B. Braem and R. Sutton-Spence (Hamburg: Signum), 69–87. doi: 10.1111/cogs.12868

Thierfelder, P., Wigglesworth, G., and Tang, G. (2020). Sign phonological parameters modulate parafoveal preview effects in deaf readers. *Cognition* 201:104286. doi: 10.1016/j.cognition.2020.104286

Trezek, B. J., Wang, Y., and Paul, P. V. (2011). "Processes and components of reading," in *The Oxford Handbook of Deaf Studies, Language and Education*, 2

Edn, eds M. Marschark and P. E. Spencer (New York: Oxford University Press), 99–114.

Villwock, A., Wilkinson, E., Piñar, P., and Morford, J. P. (2021). Language development in deaf bilinguals: deaf middle school students co-activate written English and American Sign Language during lexical processing. *Cognition* 211:104642. doi: 10.1016/j.cognition.2021.104642

Vinson, D. P., Thompson, R. L., Skinner, R., Fox, N., and Vigliocco, G. (2010). The hands and mouth do not always slip together in British sign language: dissociating articulatory channels in the lexicon. *Psychol. Sci.* 21, 1158–1167. doi: 10.1177/0956797610377340

Woolfe, T., Herman, R., Roy, P., and Woll, B. (2010). Early vocabulary development in deaf native signers: a British Sign Language adaptation of the communicative development inventories. *J. Child Psychol. Psychiatry* 51, 322–331. doi: 10.1111/j.1469-7610.2009.02151.x

Zwitserlood, P. (1996). Form priming. *Lang. Cogn. Proces.* 11, 589–596. doi: 10.1080/016909696386980

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# Acquisition of turn-taking in sign language conversations: An overview of language modality and turn structure

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The task of transitioning from one interlocutor to another in conversation – taking turns – is a complex social process, but typically transpires rapidly and without incident in conversations between adults. Cross-linguistic similarities in turn timing and turn structure have led researchers to suggest that it is a core antecedent to human language and a primary driver of an innate "interaction engine." This review focuses on studies that have tested the extent of turn timing and turn structure patterns in two areas: across language modalities and in early language development. Taken together, these two lines of research offer predictions about the development of turn-taking for children who are deaf or hard of hearing (DHH) acquiring sign languages. We introduce considerations unique to signed language development – namely the heterogenous ecologies in which signed language acquisition occurs, suggesting that more work is needed to account for the diverse circumstances of language acquisition for DHH children. We discuss differences between early sign language acquisition at home compared to later sign language acquisition at school in classroom settings, particularly in countries with national sign languages. We also compare acquisition in these settings to communities without a national sign language where DHH children acquire local sign languages. In particular, we encourage more documentation of naturalistic conversations between DHH children who sign and their caregivers, teachers, and peers. Further, we suggest that future studies should consider: visual/manual cues to turn-taking and whether they are the same or different for child or adult learners; the protracted time-course of turn-taking development in childhood, in spite of the presence of turn-taking abilities early in development; and the unique demands of language development in multi-party conversations that happen in settings like classrooms for older children versus language development at home in dyadic interactions.

KEYWORDS

turn-taking, language modality, pragmatics, language acquisition, sign languages

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## Introduction

The task of transitioning from one interlocutor to another in conversation – taking turns – is a complex social process. Interlocutors who do not have the floor must process and comprehend ongoing turns, accurately anticipate when the person occupying the floor will provide an opportunity or solicit an opening for a turn shift, and, simultaneously, plan their own contribution (De Ruiter et al., 2006; Levinson, 2016). Following a turn change, interlocutors are expected to provide a turn that is both temporally and semantically contingent; language users assume that turns will change rapidly and that sequential turns will be related to prior utterances.

In spite of the social and cognitive demands, turn-taking in adult conversations often proceeds smoothly and with considerable efficiency (Sacks et al., 1974; Stivers et al., 2009; Levinson and Torreira, 2015). And where breakdowns in interaction occur, they are typically remedied or repaired rapidly (Dingemanse et al., 2015). The presence of turn-taking abilities early in both ontogeny and phylogeny, as well as the cross-linguistic consistency of turn-taking patterns and timing, has led some researchers to suggest that it is a core antecedent to human language and a primary driver of an innate "interaction engine" that underlies cross-linguistic similarities in some aspects of conversational exchange (Levinson, 2006, 2019).

In this article, we consider evidence that this "universal" human skill extends across linguistic modalities, from oral/aural spoken languages to visual/manual signed languages, as well as evidence for the presence of turn-taking abilities early in infancy for hearing children acquiring spoken languages. Based on the literature on turn-taking across modalities and in development, we discuss predictions for the development of turn-taking for deaf[1] and hard of hearing (DHH) children acquiring signed languages. Prior work offers suggestions about the implications of language modality and development for turn-taking, but we also introduce considerations unique to signed language development – namely the heterogenous ecologies in which signed language acquisition occurs for DHH children.

The communicative ecologies for language acquisition that DHH children encounter vary across numerous characteristics but we focus on variation in two aspects: setting/interlocutors and language type. In terms of the settings for sign language acquisition, we discuss the difference between language acquisition at home with family members versus language acquisition at school with teachers and peers. In terms of language type, we discuss sign languages that vary along the following dimensions: the age of the language, the size of the community of users, the existence and availability of deaf education, access to medical technologies like hearing aids and cochlear implants, as well as prevailing ideologies about "best practices" for language development of DHH children. Although a variety of terms have been proposed to categorize sign languages,[2] for this article we will use the term *local sign languages*, often from smaller communities of signers with a shorter history of use, that are used primarily in the home or informal settings, in contrast with *national sign languages*, often used by larger, geographically dispersed communities of signers with a longer history of use both at home and in institutional settings like schools. We review the acquisition of turn-taking for DHH children in three settings – two settings from communities with a national sign language and one setting from communities where there is no national sign language in use. In communities with a national sign language, we discuss: family socialization of national sign languages at home and classroom socialization of national sign languages at school. In communities without a national sign language, we discuss family socialization of local sign languages at home. We suggest that there are unique challenges for each of these groups of DHH children, based on their differential access to the language in their environment with a particular focus on three factors that could significantly impact the trajectory of turn-taking development in DHH children learning a sign language. These factors include: (1) language modality—acquiring a visual/manual language, (2) ontogeny—development as a child learner, and (3) socio-cultural factors—characteristics of the acquisition ecology. We suggest that more work is needed to account for the diverse circumstances of language acquisition for DHH children and to consider the role of both modality and unique socialization contexts for the learning of turn-taking in conversation. In particular, we encourage researchers to consider: visual/manual cues to turn-taking and whether they are the same or different for child or adult learners; the protracted time-course of turn-taking development in childhood, in spite of the presence of turn-taking abilities early in development; and the unique demands of language development in multi-party conversations that happen in settings like classrooms for older children versus language development at home in dyadic interactions.

We begin with an overview of studies of turn-taking structures in signed language conversations between adults (see section "Documenting Turn-Taking Structures in Sign Languages") then discuss studies that have explored modality effects on turn-taking timing and cues by comparing spoken and signed languages directly using either experimental or naturalistic adult conversational data (sections "Language

1 We use "deaf" and the acronym DHH to refer to children with a range of hearing thresholds and speaking or signing preferences. In some research on DHH people, it has been common practice to capitalize the word "Deaf" when referring to members of the deaf signing community, this practice has been debated in more recent work (Kusters et al., 2017; Pudans-Smith et al., 2019). In cases where we discuss studies in which the authors make the d/Deaf distinction in their work, we maintain their usage of "Deaf."

2 See Hou and de Vos (2022) for a recent discussion of terminological distinctions in sign language research.

Modality and Turn-Taking: Turn Timing" and "Language Modality and Turn-Taking: Cues to Turn Changes"). We then turn to studies of turn-taking in acquisition, providing a brief overview of work on turn-taking development in spoken language acquisition (section "Acquiring Turn-Taking Structures: Spoken Language Development"). In the final section we discuss sign language acquisition in the three social ecologies introduced above: (1) acquisition of a national sign language at home; (2) acquisition of a national sign language at school; and (3) acquisition of a local sign language at home. While there have been few studies dedicated to turn-taking in sign language acquisition, we review studies of interactional skills necessary for turn-taking like attention-getting and we discuss areas where future work could provide important insights for turn-taking development in the visual-manual modality.

## Documenting turn-taking structures in sign languages

While many researchers of social behavior (along with travelers and language users who have encountered other dialects and languages) have expressed intuitions that turn-taking patterns vary widely across cultures and languages, the broader paradigm of alternating turns between two or more interlocutors in many tasks, conversation or otherwise, seems to be a human universal (Levinson, 2006, 2019). The tension between "innate" universal principles that guide all interaction and local standards for conversational exchange is evident in much of the work on turn-taking, particularly in the substantial body of work on turn-taking in spoken languages. Early work focused on both the behavioral cues (Yngve, 1970; Duncan, 1972; Duncan and Fiske, 1977) associated with turn shifts, as well as the broader principles (Sacks et al., 1974) governing turn alternations. Recent studies have explored the psycholinguistic mechanisms underlying turn-taking practices (Garrod and Pickering, 2015; Levinson and Torreira, 2015) as well as the multimodal aspects of turn-taking (Mondada, 2019). Much of this work suggests that the general principles of turn-taking should apply broadly to all language encounters. As such, these general principles should extend across modalities to sign languages. Studies of turn-taking in signed language conversations have attempted to evaluate the compatibility between patterns observed in signed interactions and those described for spoken languages. Multiple studies that have documented the cues associated with turn-taking in naturalistic sign language conversations between adults. As mentioned above, children will have to notice and acquire these cues in development. Several of these studies are summarized in **Table 1**.

Due to the time-intensive nature of collecting and annotating sign language conversation data, studies often involve a limited number of participants and use fewer than five conversations as their dataset, many use a single dyadic or multiparty conversation (see **Table 1**). These studies consist of descriptive analyses (Baker, 1977; McIlvenny, 1995; Coates and Sutton-Spence, 2001) as well as quantitative studies of specific turn-taking phenomenon like overlaps (McCleary and de Arantes Leite, 2013; Girard-Groeber, 2015), polar questions (de Vos et al., 2015); and sign holds (Groeber and Pochon-Berger, 2014; Cibulka, 2016). These studies and their findings are discussed in greater detail below.

In a descriptive study based on data from two conversations in American Sign Language (ASL), Baker (1977) identifies a set of prosodic cues and practices that characterize initiating a turn, continuing or maintaining a turn, and signaling a shift in turn. These cues and practices vary based on whether the signer is the producer or addressee and are summarize in **Table 2**.

The prosodic cues that Baker identifies primarily relate to the position of the signers' hands, their eye gaze, and their signing size and speed.[3] She describes three possible rest positions for signers' hands, including full-rest, half-rest, and quarter-rest (Baker, 1977, p. 219), noting that a signer often signals their intention to interrupt or initiate a turn by altering the position of their hands (from full-rest or half-rest) and by changing their palm orientation. Significantly, many of the cues that Baker identifies have been excluded in subsequent studies of sign language conversations. Many studies exclude "preparatory" movements of the hands and arms when attempting to measure turn timing, for example. Thus, it remains unclear whether these cues are significant for signers, regardless of their age.

Many of the cues from Baker serve different functions depending on who produces them – *producer* or *addressee*. For example, if the *addressee* makes and/or maintains eye contact with the producer (+)Gaze, this suggests that they are ready for the producer to initiate or continue a turn. If the *producer*, however, makes eye contact with the addressee (+)Gaze, it often means that they are about to yield their turn. For child signers, this means they must acquire a complex set of signals that are contingent on their current status in an interaction. If a child signer is an addressee, making eye contact with their interlocutor (+)Gaze, will indicate something different than if they were currently the active signer.

Later studies have contested some of the claims in Baker. In their study of British Sign Language (BSL) conversations, for example, Coates and Sutton-Spence suggest that prior work on conversation structure, particularly turns, focused too much on conversations between dyads and conversations in formal settings like classrooms (p. 526). This led sign

3 We thank a reviewer for pointing out that cues to turn-taking have also been studied for tactile sign (Mesch, 2002). A recent study also explores turn-taking in conversations with deaf-blind signers of Bay Islands Sign Language Ali et al. (2021).

TABLE 1 Studies of turn-taking in national sign languages.

| Study | Language(s) | *N* participants | Data source | Turn-taking behavior(s) |
|---|---|---|---|---|
| Baker, 1977 | American Sign Language (ASL) | 4 | 2 conversations (dyads) | Descriptive (transcripts) |
| Cibulka, 2016 | Swedish Sign Language (SSL) | 42 | Free dyadic conversations, 20 sessions (1 h 50 min) | 70 instances of sign suspension[1] |
| Coates and Sutton-Spence, 2001 | British Sign Language (BSL) | 8 | 2 conversations (multiparty) | Descriptive (transcripts) |
| de Vos et al., 2015 | Sign Language of the Netherlands (NGT) | 16 | 6 dyadic conversations<br>1 triadic conversation (11 h) | 190 questions<br>104 polar questions<br>86 content questions |
| Girard-Groeber, 2015 | Swiss German Sign Language (DSGS) | 4 | 1 multi-party conversation (33 min) | 382 overlaps, (reduced to 331 based on eye contact) |
| Groeber and Pochon-Berger, 2014 | Swiss German Sign Language (DSGS) | 3 | 1 multi-party conversation (90 min) | 84 turn-final holds produced by one of three students |
| Manrique and Enfield, 2015 | Argentine Sign Language (LSA)<br>Corpus | 23 | Informal dyadic, multi-party conversations (1 h 50 min) | 23 instances of "freeze look"[2] (original dataset: 213 instances of Other-Initiated-Repair (OIR) |
| McCleary and de Arantes Leite, 2013 | Brazilian Sign Language (Libras) | 2 | 1 conversation (dyad) (3 min) | 4 examples of overlap or near overlap |
| McIlvenny, 1995 | Finnish Sign Language (FiSL) | Not reported | Dyadic, multi-party conversations | Descriptive (transcripts) |

[1] Cibulka (2016) uses the term "sign suspension" to describe "moments in signed interaction when sign production is temporarily suspended" (p. 448). He notes that suspensions happen for a variety of reasons (overlap in turns, forgetting a sign, etc.) and documents the ways that they are resolved in interaction.
[2] "Freeze look" is the term that Manrique and Enfield use for a behavior observed in signed conversations when a signer has been asked a direct question and "holds still while looking directly at the questioner" (3). They argue that this a strategy for other-initiated repair in conversation, and prompts the signer to repeat their original question.

TABLE 2 Turn cues from American Sign Language (ASL) identified in Baker (1977).

| | | Sign producer | Sign recipient |
|---|---|---|---|
| Signers' hands | Initiate turn | Raise hands out of rest position | Maintain own inactivity |
| | Continue/maintain turn | Not returning to rest position | Backchanneling (head nodding, smiling, postural shift, facial activity suggesting surprise, agreement, uncertainty, and lack of understanding) |
| | Shift in turn | Return to rest position | • Move out of rest position<br>• Wave, index to producer, touching, initiating first turn, repeating first few signs until producer has yielded floor or suppressed turn-claim |
| Signers' gaze | Initiate turn | (−)GAZE if statement<br>(+)GAZE if question | (+)GAZE |
| | Continue/maintain turn | (−)GAZE | (+)GAZE |
| | Shift in turn | (+)GAZE (if not already (+)GAZE) | Switch to (−)GAZE, when speaker is (+)GAZE |
| Optional cues | Initiate turn | • Wave to addressee<br>• Index to addressee<br>• Head/postural lean forward | |
| | Continue/maintain turn | • Increase in signing speed<br>• Fill pause with movement<br>• Hold last sign | • Index (point) to producer<br>• Short repetitions of some of the producer's signs |
| | Shift in turn | • Decrease signing speed near end of turn<br>Call for response:<br>• Palm up toward addressee<br>• Indexing addressee (end of turn)<br>• Holding last sign (questions)<br>• Raising last sign (questions)<br>Question intonation (face or body) | • Increase in size/quantity of backchanneling<br>• Palm orientation change |

language researchers (e.g., Baker, 1977; Mather, 1996) to assert that signers obligatorily establish eye contact with their interlocutor(s) prior to initiating a signed turn. Coates and Sutton-Spence suggest that this may have been stated too strongly, and could be rephrased, "By 'cannot' [start a turn without eye contact] they clearly mean that optimum communication will not occur without the elaborate attention-getting they describe… we must understand Baker's and Mather's use of 'cannot' to mean 'it would not normally make communicative sense for a signer to initiate a turn without eye contact with the addressee'" (513).

In a study focused on the sequential context of turn overlaps in Swiss German Sign Language (DSGS), Girard-Groeber (2015) explored whether overlaps in sign language conversations occurred in "orderly" or predictable places in turns, as suggested for spoken language conversations (Jefferson, 1984, 1986). In particular, they asked whether sign turn overlaps tend to happen in the middle of *turn construction units* (TCUs) or if they were more common at *turn relevance places* (TRPs) and possible points of completion. In the DSGS conversation that Girard-Groeber analyzed, signers overlapped most frequently at TRPs and possible points of completion (79.4% of all overlaps).

Girard-Groeber found substantial overlap of signed turns, even though only turns that overlapped the stroke phase of signs were included in the analysis. If a signer raised their hands to prepare to sign as another signer occupied the floor, this was excluded from the analysis because it was considered the preparatory phase of the sign. This finding contradicts some earlier claims about the significance of the current signer terminating a turn by returning their hands to a full "rest position." Girard-Groeber (2015) noted that signers often did not wait for the current signer to fully relax their hands, "Rather they fine-tune their turn-beginnings to the end of grammatical and prosodic units" (p. 205), a pattern noted for spoken languages as well (Selting, 1996). Based on Girard-Groeber's claim, child signers may not be able to use hand position as a reliable cue to turn transitions (if they are expected to begin turns before their interlocutor has lowered their hands fully to a rest position). In spite of the finding that signers frequently overlapped their turns, Girard-Groeber suggests that these overlaps are "orderly," happening at predictable moments in the conversation, and that signers are, therefore, still orienting to the "minimal overlap, minimal gap" principle discussed in the introduction.

McCleary and de Arantes Leite (2013) also argue that signers of Brazilian Sign Language (Libras) are motivated by the one-at-a-time or "minimal gap, minimal overlap" principle, based on an analysis of four examples from a conversation between two friends. They identify several "overlap resolution devices" (ORD's), including: emphatic articulation of a sign to attract the attention of an interlocutor (p. 140), slowed signing speed (when one signer notices that his conversation partner has initiated a shrug and palm-up gesture) (p. 135), abruptly cutting off a sign (p. 135), explicitly asking for a partners attention with a wave or sign (p. 144) and lastly, lexically marking the start of a long turn with particular lexical items, like the sign "example" (p. 144).

Studies of naturalistic signed language conversations between adults generally suggest that there are specific signals associated with turn transitions as well as strategies for resolving overlapping turns when they occur, and while there is some evidence that turn overlaps happen frequently in signed conversations, it seems that these overlaps happen in similar places in conversational turns to spoken languages. We now turn to corpus and experimental studies that have compared spoken and signed language data directly to explore modality effects for two aspects of turn-taking: turn timing and cues to turn changes.

## Language modality and turn-taking: Turn timing

The study of turn-timing affords researchers a way to quantify and compare across disparate languages and social settings; but researchers face a challenge when determining what unit should be measured and compared. Early studies pointed out a basic principle of turn-taking—turn-length is rarely pre-determined in conversations. Regardless of the length of the preceding utterance, however, the transition between interlocutors happens across conversations and circumstances. In terms of timing, this transition could occur in one of three ways, (1) interlocutors could transition turns seamlessly, with no gap; (2) interlocutors could transition turns but there could be a gap with no speaking or signing; (3) interlocutors could overlap their turns, for a number of reasons, including (but not limited to) confusion about who will next occupy the floor, failure to end a turn when expected, or interruptions. Sacks et al. (1974) suggested that, in general, turn transitions are guided by a *one-at-a-time principle* such that language users use strategies to minimize gaps and overlaps between turns.

### Turn timing in spoken language conversations

Stivers et al. (2009) tested the *one-at-a-time principle* in a comparative study of ten languages that varied in their linguistic type (word order, sound structure, and grammar) as well as contexts of use (social structure). Using video recordings of naturalistic conversations, they measured the "response offset" – the temporal relationship between turns – in polar question-response sequences.

In their sample, response offsets were brief – for all languages in the dataset the mean was +208 ms – however there was a continuum of faster versus slower average response offsets across the sample (Japanese speakers had the fastest mean time for turn transitions at 7.29 ms while Danish speakers had the slowest at 468.88 ms). They found that four factors, including: answering, response type, non-verbal behaviors, and the presence of speaker gaze were significant predictors of response offset variation independent of the language spoken. Confirmation responses were faster than disconfirmation, responses with non-verbal behaviors (head nods, shakes, and squints) were faster than vocal-only responses, and responses were faster when the questioner gaze was directed to the addressee. Overall, Stivers et al. (2009) concluded that their data support a "universal system hypothesis," (p. 10,589) and that users of all the languages they surveyed attempted to minimize both overlaps of turns and gaps between turns as predicted by Sacks et al. (1974).

Even though response offsets may be quantitatively similar across diverse communities of language users, humans appear to be remarkably attuned to the timing patterns in the language they use most often. Thus, within the overarching principle of "minimal gap, minimal overlap" (Schegloff, 2016), even small shifts in response offsets are perceived as significant divergences for language users from outside that community, "speakers of all languages aim at minimizing significant delays relative to the specific rhythm of that language in conversation. . . what constitutes a subjectively notable delay involves greater absolute duration in some languages than in others" (Stivers et al., 2009, p. 10590). Further, it remains to be established whether the patterns observed in the Stivers, et al. study extend to other utterance types (recall that they limited their dataset to polar question-response sequences) and across language modalities.

## Turn timing in sign language conversation

In a subsequent study, de Vos et al. (2015) explored whether Stivers et al.'s claim of a "universal system hypothesis" for turn-taking extended cross-modally. The researchers conducted a quantitative analysis of turn-timing in Sign Language of the Netherlands (NGT). As in Stivers et al. (2009) the sample was limited to polar question-answer pairs.

Similar to previous studies of sign language turn-taking, researchers encountered challenges when measuring sign length and identifying sign boundaries. This challenge of what "counts" in measures of turn boundaries is not limited to signed languages. Although gestural cues and inbreaths have been considered potential cues to turn units in oral/aural languages, Schegloff (2000) excludes them, describing them as "preparation for speaking but not part of speaking" (p. 50). Researchers have suggested that "preparatory movements" or the articulators (hands and arms) in sign languages are analogous to inbreaths (McCleary and de Arantes Leite, 2013, p. 133), and have thus excluded them from their analyses.

In de Vos et al. (2015), researchers compared two measures of sign boundaries (see **Table 1** for participant and study information). The first method for annotating signs, termed "sign-naïve boundaries," accounts for all movement phases of a sign. Phases were annotated based on gestural coding system from Kendon (1972, 1980, 2004) and Kita et al. (1998) and included: preparation, stroke, hold, and post-utterance retraction. The second method for annotation signs, termed "stroke-to-stroke turn boundaries" measures a sign for only the "stroke" movement phase that is "lexically specified." Researchers coded from the last frame at which the lexically specified handshape was formed for the sign, stating "the start of the initial stroke (the 'content' part of the manual gesture) as the turn beginning as it most directly reflects the phonological content of a sign" (de Vos et al., 2015, p. 2). de Vos et al. use these measures to explore whether there are significantly more overlaps in signed conversations compared to spoken conversations and whether turn overlaps last longer or have a similar duration to overlaps in spoken conversation turns.

The proportion of turns that overlap, based on "sign-naïve turn boundaries" in the NGT sample is 82.2%. This proportion is significantly higher than the proportion of overlapping turns in the cross-linguistic spoken languages sample from Stivers et al. (2009) (which ranged from 13.5% overlapping turns for spoken Lao to 40% overlapping turns for spoken Japanese). The proportion of turns that overlap based on "stroke-to-stroke" boundaries was 29.8%, which was not significantly different from the spoken languages sampled. Similar differences were found for turns that had a significant gap (more than 120 ms). See **Table 3** for a summary of turn overlaps and gaps from the study.

When de Vos et al. compared "sign-naïve" and "stroke-to-stroke" measures of turn timing directly, they found turn offsets based on "sign-naïve boundaries" had, on average, lengthy overlaps between turns (mean −812 ms, negative boundary measures reflect overlapping turns). When turn offsets were based on "stroke-to-stroke" turn boundaries, there were, on average, short gaps between turns (mean 307 ms, positive boundary measures reflect a gap between turns) (see **Table 4**

TABLE 3 Turn overlaps and gaps in Sign Language of the Netherlands (NGT) versus spoken languages.

| Language | Turns with significant overlap* | Turns with significant gap* |
|---|---|---|
| NGT (sign naïve) | 0.82 | 0.58 |
| NGT (stroke-to-stroke) | 0.30 | 0.17 |
| Spoken Japanese | 0.40 | 0.41 |
| Spoken Dutch | 0.31 | 0.49 |
| Spoken Lao | 0.13 | 0.73 |
| Spoken Danish | 0.16 | 0.72 |

*"Significant" gap/overlap duration threshold from Heldner (2011), based on a sample of spoken Dutch, judged by native Dutch speakers.
Data for NGT are from: de Vos et al. (2015, pp. 7–8).
Data for spoken languages are from: Stivers et al. (2009) and Heldner (2011).

TABLE 4 Turn timing in Sign Language of the Netherlands (NGT) versus spoken languages.

| Language | Mean turn transition time (ms) |
|---|---|
| NGT (sign naïve) | −812 |
| NGT(stroke-to-stroke) | 307 |
| Spoken languages (all languages) | 208 |
| Spoken Japanese | 7 |
| Spoken Dutch | 109 |
| Spoken Lao | 420 |
| Spoken Danish | 469 |

Data for NGT are from: de Vos et al. (2015, pp. 7–8).
Data for spoken languages are from: Stivers et al. (2009) and Heldner (2011).

for comparison of turn timing with data from Stivers et al., 2009). This finding underscores the implications of decisions made for annotating signs. If signs are annotated one way (using "sign-naïve" boundaries), sign languages have a very different distribution from spoken languages, specifically when using this method, sign language conversations appear to have longer overlaps and more frequent overlaps than spoken language turns. If signs are annotated using a different method (using stroke-to-stroke boundaries), then the distribution of turn overlaps in sign language conversations looks similar to spoken language conversations – there are relatively few overlaps and they are short in duration. The challenge of when signs should be considered to start or stop (and as a result, overlap) thus has significant effects on the analysis of sign turns.

The findings from the NGT sample of polar questions, both in terms of precise timing of turns and the resulting proportion of turns with significant overlaps or gaps (again, based on a threshold of 120 ms) led the authors to conclude that "…it is therefore plausible that preparatory and retraction movements in signed conversation are best seen as parallel to the pre-beginnings and post-completion elements of spoken turns (cf. Schegloff, 1987), and that TRPs [turn relevance places] are best approximated by the end of the last stroke" (de Vos et al., 2015, p. 9). Although this study of sign language turns offers a detailed, quantitative analysis of turn timing, it is one of the few studies that attempts to quantify sign turn timing. It would be useful, in future studies, to use a cross-linguistic sample, similar to that studied for spoken languages (Stivers et al., 2009) to assess whether, similar to spoken languages, sign languages have consistent turn timing cross-linguistically.

Quantitative studies of turn-taking in national sign languages highlight the challenges of directly comparing spoken and signed languages, particularly when using precise measures for timing. Analyzed one way, the NGT sample suggests that overlapping turns in sign language conversations are more frequent and last longer than spoken language overlaps. But analyzed differently, NGT looks very similar to spoken languages, both in its exact timing and in the proportion of turn changes with overlaps and gaps. For DHH children acquiring a sign language, the results are somewhat inconclusive about the relationship between language modality and turn-timing. If children are attentive to the "stroke-to-stroke" cues that de Vos et al., coded, then they will be acquiring a system with similar timing patterns to spoken languages. If, however, they use cues like the preparatory movements of signers' hands and arms or gaze, then it could be argued that they are acquiring a system with considerably more overlapping of turns than spoken language exchanges.

## Language modality and turn-taking: Cues to turn changes

Studies of turn timing have explicit criteria for isolating the unit of analysis: the person currently holding the floor finishes a turn and shifts to a different signer or speaker, but it has been harder for researchers to isolate and measure the cues that language users are producing and perceiving to anticipate turn beginnings and ends. When there is an exchange of turns, it is possible to measure the offset – gap or overlap – between language users. This consistency in the unit of analysis enabled researchers to compare across languages directly, both in a large cross-linguistic sample, and across language modalities between signed and spoken languages.

Early work by Sacks et al. (1974), mentioned above, proposed that there were two units that existed –TCUs and TRPs, where turns exchanges were possible (but not necessary). The original description of these units was quite vague, "Unit-types for English include sentential, clausal, phrasal, and lexical constructions" (Sacks et al., 1974, p. 702) and despite the broad list of possible unit types, much of this early work emphasized syntactic units as the primary cue to turn completion. In a subsequent study, however, using naturalistic conversational data, Ford and Thompson (1996) showed that TCU in spoken language conversations depended on a combination of syntactic, intonational and pragmatic cues. Further studies explored other turn cues, including pauses (Maynard, 1989), and prosody (Local and Kelly, 1986; Couper-Kuhlen and Selting, 1996; Caspers, 2003). Additional cues that undoubtedly play a role in cueing turns in face to face interaction come from the co-speech gestures that speakers produce. Much of the early work in conversation analysis on turn structure used telephone calls, precluding co-speech gestures as a source of turn information (Sacks et al., 1974). However, there is also a substantial body of work on the role of non-verbal cues in interaction, including eye gaze and gestures (Kendon, 1967; Goodwin, 1981; Bolden, 2003; Rossano, 2013). Due to space constraints, here we focus primarily on linguistic cues to turn structure, but note that non-verbal cues for conversational turns may be particularly critical for DHH children in hearing/speaking families. In the next section, we review studies that have developed experimental paradigms to directly test the role of different kinds of cues for turn prediction.

## Turn cues in spoken language conversations

In studies assessing the role of different kinds of cues for conversational turns, researchers often manipulate language data to control the amount of prosodic and lexical information participants can access. For example, by flattening the intonational contour of a recorded spoken language conversation. Participants are then asked to press a button when they think the current speaker has finished their turn (De Ruiter et al., 2006). In their study using naturalistic conversations recorded in Dutch, De Ruiter et al. (2006), found that participants were able to accurately predict the end of speakers' turns when listening to audio with flattened pitch. Participants were less accurate at predicting the ends of turns when they had access to the intonational contours but not the lexicosyntactic information in the conversations. These results led the authors to conclude that for adult speakers, lexicosyntactic information is necessary, and possibly sufficient, for predicting turn ends. Most studies corroborate this finding for the role of lexicosyntactic information, but it is difficult to disentangle prosody from syntax (Ford and Thompson, 1996). A later study that varied both syntax and intonational cues (Bögels and Torreira, 2015) found that participants used information from both lexicosyntactic boundaries and intonational phrases to determine when turn ends would happen, and that they frequently produced errors when intonational phrases suggested a turn end in the midst of multi-utterance turns. In a study of English-speaking adults and children (discussed more in section "Acquiring Turn-Taking Structures: Spoken Language Development" below), Casillas and Frank (2017) also found that participants used both lexicosyntactic and prosodic information as cues to turn changes. Experimental studies of turn-taking are difficult in part because of the effort required to generate naturalistic stimuli. As a first step, researchers must get recorded language data that approximates natural conversation, but can be recorded and subsequently edited to change the information available from lexical content or prosodic content. In the next section we discuss the first study that attempts to use a similar method for sign language data.

## Turn cues in sign language conversations

Due to the difficulty of constructing stimuli, as well as recruiting participants, there have been very few studies of turn prediction in sign languages. Here we review de Vos et al. (2022), one of the first studies that uses similar methods to the studies discussed above, in which participants viewed signed naturalistic dyadic conversations between adult signers of NGT and pressed a button when they thought the current signer was about to end their turn. The researchers compared signers and non-signers to determine (1) whether participants could accurately anticipate turn ends, (2) whether participants were more likely to anticipate turn ends that contained questions, and (3) whether signers were more likely to anticipate turn ends in questions that included non-iconic question markers (lexical items) from NGT. They found that all participants (early-exposed signers, late-exposed signers, and non-signers) were able to accurately predict the ends of turns in the clips from NGT conversations. All participants were also more accurate for trials that contained questions. However, only early-exposed signers were significantly better at anticipating turn ends marked with NGT question lexical items. The researchers suggest that their findings lend support for Levinson's (2006) interaction engine hypothesis because even non-signers who did not have any experience with NGT were sensitive to communicative intent in signed conversations. There also seems to be a widespread sensitivity to questions, or "response-eliciting" cues, above and beyond language-specific elements like lexical items.

For DHH children acquiring a sign language, this finding suggests that learners will have access to some cues for turns, even without early exposure to a sign language. They will not, however, be able to access all of the necessary cues without a language model and linguistic input.[4] In particular, non-iconic lexical items that are not based on gestural patterns in the speech community, will not be available to them. Thus far we have focused on the relationship between turn-taking and language modality, but turn-taking patterns also vary across development or acquisition. We provide a brief overview of the work on acquisition of turn-taking in spoken languages before we introduce work on turn-taking and related communicative skills in signed language acquisition.

# Acquiring turn-taking structures: Spoken language development

Beginning in the 1970s, a considerable body of work was developed focusing on the development of turn-taking in early childhood (Bates, 1976; Snow and Fergueson, 1977; Ervin-Tripp, 1979; Ochs and Schieffelin, 1979; Garvey and Berninger, 1981). Here we discuss studies that have focused on the same

4 Here we refer to DHH children in hearing/speaking families. Although these children may have limited or reduced access to the linguistic information in the spoken language around them, they will still be able to access some of this input, as well as the co-speech gestures that speakers produce (see Koulidobrova and Chen-Pichler, 2021, for a discussion of diverse early language experiences of DHH children in hearing/speaking contexts).

aspects of turn-taking reviewed for adult language users: turn timing and turn cues.

The onset of turn-taking in infancy and childhood was initially debated, some early work debated the agency of infant children, who were observed to exchange vocally with caregivers well before they were able to produce language (Snow, 1977). Researchers have since taken measurements based on audio recordings of these exchanges to show that infants appear to be agential, "responding" rapidly to their mothers' vocalizations with timing that suggests their vocalizations are contingent on, or responding to, their mothers' (Gratier et al., 2015; Hilbrink et al., 2015). In **Table 5**, we present some of the timing data that have been reported from longitudinal studies across development of children engaged in different configurations of dyadic conversation, including adult–child and child–child interactions.

Recalling that on average adult speakers have a 200 ms gap between turns, it is clear that children are slower than adults in their early vocal exchanges. And while turn timing may not be entirely driven by adult communication partners, children do appear to be affected by their interlocutor, based on the gap times reported by Garvey and Berninger (1981) for conversations between 2- and 3-year-old child peers (900–1500 ms). The timing of gaps seems to be tightly connected to children's developing communicative and linguistic competence – both Hilbrink et al. (2015) and Casillas et al. (2016) find that children slow down at critical points in development when they may be developing new communicative skills or engaging in more complex linguistic production.

Hilbrink et al. (2015) examined the gap duration between turns beginning at 3 months until the children were 18 months old. While the timing of mothers' responses to their infants' vocalizations remained relatively stable across the study, infant response time varied significantly across development. Infants initially responded quickly to their mothers' vocalizations (range of 345–902 ms at 3 months), but they slowed down around nine months (542–3,297 ms). The authors attribute the increase in gap timing around nine months to developmental changes in infants "communicative and social understanding of interactions" (p. 255).

Based on a dataset of naturalistic conversations from 5 caregiver-child dyads between ages 1;8 and 3;5, Casillas et al. (2016) documented the gradual development of rapid turn-taking. The timing of turns was closely related to both the child's age and the complexity of the turn. Children were able to reply more quickly to simple questions (yes/no) at younger ages and gradually developed the ability to respond to more complex questions across development. Casillas et al. suggest that increasingly complex questions from caregivers – and the increasingly complex answers they require – may entail more processing demands for the children. The authors note the dual contribution of comprehension –understanding the question– and production –formulating an answer – to processing demands on child speakers.

Studies of spoken language interactions with young children thus suggest that children do have the capacity to intentionally engage others from a very young age, prior to their ability to produce or comprehend language, lending support for the universal "interaction engine" (Levinson, 2019). However, this does not yield a straightforward ability to immediately engage in adult-like conversation. For DHH children acquiring a sign language, this work suggests that child signers may have precocious abilities to engage in alternating turns early in development, but also that they may not look exactly like adult signers in conversation until later in development. So far, no studies that we are aware of have attempted to measure turn timing in sign language conversations with children, a point we return to in the discussion.

In a study of children's ability to anticipate turn changes, Casillas and Frank (2017) showed participants (both child and adult English speakers) videos of dyadic conversations between two speakers of one of five languages (English, German, Hebrew, Japanese, or Korean). The non-English conversations were used to provide participants with non-lexicosyntactic cues to turn boundaries (e.g., prosody, gesture, and phrase-final lengthening). Similar to studies comparing different cue types discussed in sections "Turn Cues in Spoken Language Conversations" and "Turn Cues in Sign Language Conversations" above, these stimuli were intended to test the role of lexicosyntactic and prosodic information as cues to turn exchanges, within the context of naturalistic conversation. Importantly, these stimuli also included gestural information since they were video conversations, unlike prior studies which involved listening to audio recorded conversations and pressing a button.

TABLE 5 Timing data (gap length between turns) from infants and children in conversation.

| | 0;4 | 0;9 | 1;6 | 1;8–1;9 | 2;4–2;5 | 2;10–3;3 | 3;0–3;1 | 3;3–3;5 |
|---|---|---|---|---|---|---|---|---|
| Mother–infant[1] | 326–921 | 542–3,297 | 485–1,270 | | | | | |
| Caregiver–child[2] | | | | 844–1,017 (867) | 446–1,738 (686) | | 357–894 (571) | 292–619 (523) |
| Child–child[3] | | | | | | 900–1,500 | | |

[1] Mother–infant data are from Hilbrink et al. (2015), range of median gap time for infants, measured in ms.
[2] Caregiver–child data are from Casillas et al. (2016), shortest and longest mean gap for children, mean gap for all children in parentheses, measured in ms.
[3]Child–child data are from Garvey and Berninger (1981), median "switching pause" values in ms.

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All participants in the study were affected by turn type (question versus non-question); they made more anticipatory gaze switches following questions. Children (child participants ranged in age from 3;0 to 5;11) were also affected by the language used in the video. Younger children made more anticipatory gaze switches while watching clips from English conversations than non-English conversations, suggesting that children need access to lexicosyntactic information to predict the ends of turns, but as they develop they get better at making use of non-lexicosyntactic information. Contrary to prior findings that children rely primarily on lexical or syntactic information to predict turn endings, this study suggests that children (and adults) have alternative strategies to predict the ends of conversational turns when lexical or syntactic information is unavailable to them.

In a follow-up study that more closely controlled the amount of prosodic and lexical information available to participants, Casillas and Frank (2017) found that young children (1;0–6;11) were spontaneously able to make turn predictions by age 2;0. Even at age 6;0, however, children were not as accurate at adults in their turn behavior predictions. The researchers conclude that children are aware of turn cues from a very young age, but develop an ability to make predictions based on these cues gradually across development. In particular, they emphasize that children seem to need access to lexical information, whether a turn contains a question or not, to achieve adult-like prediction behaviors and reiterate that it takes children several years to fully integrate all of the cues that contribute to effective turn taking monitoring and responsiveness.

Together with the results from studies of sign language turn prediction, studies of child speakers would suggest that DHH children should have some ability to anticipate turn changes in sign conversations from a young age. However, their ability to achieve adult-like efficiency in predicting turn changes will not occur until later in development. There is, further, a critical modality-based difference for DHH children acquiring a sign language versus hearing children acquiring a spoken language. While it is likely helpful for hearing children to be able to turn their head in time to see a speaker begin a turn in a spoken language conversation, DHH children will miss the linguistic signal completely if they do not direct their attention to the next signer in time to see the start of their turn. In other words, hearing children can hear a spoken language turn whether they are looking at the speaker or not, but a DHH children cannot see a signed turn if they are not looking at the signer. Whether gaze is a prerequisite of initiating a turn in adult signed conversations is somewhat contested, but for child signers this is a critical prerequisite for following and eventually entering into sign conversation. In order to follow signed conversation, child signers must recognize the cues and patterns of turns in signed turn exchanges. As noted in the introduction, researchers continue to debate whether the visual/manual modality of sign languages alters their turn-taking structure and whether this has implications for acquisition.

## Acquiring turn-taking structures: Signed language development

Spoken language acquisition happens with seemingly little effort on the part of caregivers and children. Hearing children are exposed to the language(s) spoken around them and gradually grow in their ability to comprehend and produce them. DHH children, however, are often in very different circumstances from hearing children. They are typically born into hearing families.[5] where no one knows a sign language. They may be born in a community where there is not access to a national sign language or formal schooling for the deaf. In countries with universal hearing screenings at birth, children and their families are rapidly recruited into systems with support for medical interventions like hearing aids or cochlear implants and language intervention like speech therapy or sign language classes (Mauldin, 2016). And while there is a considerable body of work documenting spoken language acquisition for DHH children, both at home and at school,[6] in this section, we focus on DHH children who are acquiring a sign language. We will explore turn-taking development for DHH children learning a national sign language at home from signing parents or grandparents; DHH children learning a national sign language at school from signing teachers and peers; and DHH children learning a local sign language at home.

### Deaf or hard of hearing children acquiring a national sign language at home

As discussed above, the majority of DHH children are born into hearing/speaking families (Mitchell and Karchmer, 2004). The small percentage of DHH children who are born to DHH signing parents offer insight into the language acquisition process when it occurs in the visual/manual modality with early and full access. In longitudinal studies of sign language development at home, researchers have observed that signed interactions between DHH parents and DHH children differ significantly from adult signed conversations. There have been several longitudinal studies of the sign language acquisition of

5 Estimates suggest that approximately 5% of DHH children in the United States are born into a family with one or more DHH parents (Mitchell and Karchmer, 2004).

6 For spoken language development of DHH children at home: Smolen et al. (2021), Arora et al. (2020), Lederberg and Everhart (2000). For spoken language development of DHH children in oral classrooms: Duncan and Lederberg (2018), Lloyd et al. (2001), Vandell and George (1981), Wood et al. (1982).

DHH children at home with DHH signing parents, the studies cited in this section are summarized in **Table 6** including the sign language used and the ages of the children observed. This is not intended to be an exhaustive list of all studies of sign language acquisition at home, but includes studies that specifically mention acquisition and development of turn-taking and attention-getting patterns in early signed interactions between DHH parents and DHH children.

In their study comparing DHH and hearing infants from different contexts (hearing and deaf signing families; data collected at 6, 9, 12, 15, and 18 months), Meadow-Orlans et al. (2004) note.

> *Clearly the pace of linguistic turn-taking in the first year of life is slower for dyads in which child and mother are deaf than for dyads in which both are hearing. This difference in pace is to be expected because deaf persons must divide their visual attention between exploring objects in the environment and receiving communications. This effect is not observed in adult conversations, but is a pervasive characteristic of signed conversations with infants and toddlers who have not yet developed the ability to make smooth changes in focus of visual attention (p. 162).*

Meadow-Orlans et al. suggest that DHH caregivers adjust the pace and timing of their turns to accommodate the visual attention of their DHH child. As discussed above, learning a sign language places different demands on the child in terms of visual attention. In contrast to spoken language input, which the hearing child can access with or without visual attention to the speaker, the child learning a sign language must see signing in order to perceive it, and they must be attentive to engage in turn-taking. Visual attention is thus a necessary prerequisite to turn-taking in sign language, and we include studies of visual attention management in this review. Studies of mother–child dyads suggest that deaf signing mothers make significant adjustments to their signing to engage their child's visual attention. There are contradictory reports in the literature, however, regarding the strategies that DHH signing mothers use with their DHH signing children.

In many studies, researchers report that deaf signing mothers seem to adopt less overt strategies for capturing and directing their DHH children's attention; this is reflected in both the amount of time that DHH mothers spent waiting for their child's attention, as well as their use of explicit attention-getting signals. In a study of four mother-child dyads,[7] Harris et al. (1989) found that mothers generally moved their signing so that it was within the child's visual field, noting, "rather than manipulating the child's focus of attention, the mothers tended to sign where the child was already looking" (p. 90). This pattern aligns with other studies of child-directed signing and a tendency to wait for the DHH child to look to the mother, rather than employ strategies to attract or redirect the child's current focus of visual attention. Meadow-Orlans et al. (2004) characterize deaf signing mothers noting, "The

7 The mothers and children were deaf and used British Sign Language, BSL (Harris et al., 1989, p. 84).

TABLE 6 Studies of sign language development of DHH children of DHH parents.

| Study | Language | *N* participants | Participant age(s) | Data |
|---|---|---|---|---|
| Harris et al., 1989 | British Sign Language (BSL) | 4 mother–child dyads, DHH mother and DHH child | Children observed at 7, 10, 16, and 20 months | Video recordings of free play (20 min) |
| Harris and Mohay, 1997 | British Sign Language (BSL); Australian Sign Language (Auslan) | 11 mother–child dyads; all DHH children; 5 DHH parents native users of BSL or Auslan; 6 hearing parents enrolled in Signed English program | 18 months | Video recorded data of child and caregiver interacting at home or in a lab setting with toys (20–40 min) |
| Holzrichter, 2000 | American Sign Language (ASL); Sign Language of Spain (LSE) | 6 DHH children with DHH parents (3 from each language) | ASL children ages 2;5–3;10<br>LSE children ages 2;1–4;2 | Video recordings of child playing with caregiver at home using toys, flashcards |
| Meadow-Orlans et al., 2004<br>data collected: 1988-89 | American Sign Language (ASL) | 20 DHH children with DHH parents<br>Subset of 80 infant/caregiver dyads:<br>20 DHH children with Hearing parents<br>20 hearing children with DHH parents<br>20 hearing children with hearing parents | Children tested at 6, 9, 12, 15, and 18 months | video recordings of free play, still face/strange situation, interviews, developmental profiles |
| Pizer et al., 2011 | American Sign Language (ASL) | 3 DHH children with at least one native signing parent | 9, 13, and 15 months (additional recordings at 17–18 months and 24 months for 2/3 participants) | 10 min of video recordings of free play |
| Swisher, 1999 | American Sign Language (ASL) | 9 dyads DHH child with DHH caregiver<br>Subset of Gallaudet longitudinal study (Waxman and Spencer, 1997; Meadow-Orlans et al., 2004) | Children observed at 9, 12, and 18 months | Video recordings of free play with toys |

picture of communication presented by Dd mothers was often one of watchful waiting and responding to their children's interests when presented with an opportunity to communicate" (160). Observations about how deaf signing mothers choose to take turns in conversation with their young deaf children are supported by quantitative evidence that deaf mothers spent significantly more time waiting on their children (70% of a 3-min face-to-face dyadic exchange) when compared to hearing mothers of hearing infants (35%) and hearing mothers of infants with a hearing loss (16%) (Spencer et al., 1992, p. 72). These studies suggest that DHH signing mothers are often willing to spend a significant amount of time waiting for their DHH child's visual attention, rather than actively seeking to change their child's focus. This is reinforced by studies exploring the use of explicit attention-seeking signs and cues.

In a cross-linguistic comparative study of deaf children (ages 2;1–4;2) in deaf signing families from Spain and the United States, Holzrichter (2000) found that deaf parents[8] used few attention-getting devices with their signing children, noting that "In general, parents of two-year-old's seemed willing to wait for their children's attention and to allow the child to set the pace of the conversation" (p. 66). Holzrichter compared 2-year-old and 4-year-old signers, reporting that all children were most likely to be engaged in mutual gaze with their parents for most turns (72–77% of turns across the sample), with parents looking away during turns with 4-year-old's more often than 2-year-old's. Holzrichter suggests that withholding or averting their gaze could be a strategy that parents of older children are using to maintain the floor, noting that the 4-year-old's were much more active contributors to conversations, introducing new topics and actively competing for the floor (p. 64).

The results from Holzrichter are compatible with findings from an earlier study by Swisher (1999) that documented attention-getting strategies in 9 ASL-using infants who were recorded interacting with their mothers at 9, 12, and 18 months. Swisher found highly variable rates of attention-getting strategies from the mothers – some frequently tapped their children, waved toys at them, or moved their signing into the child's line of vision, while others rarely engaged in these practices (see also Meadow-Orlans et al., 2004, pp. 184–186 for additional discussion of these results). Across the sample, however, children consistently became more responsive to these techniques. This was especially true for taps for attention, which were the most frequent strategy when the child was within reach of the mother. Average responsiveness to attention-getting strategies increased from 23 to 50 to 78% at 9, 12, and 18 months respectively (p. 34). Swisher notes that by 18 months, "Turn taking appeared to be more rapid, with children more often responding quickly and crisply to taps as well as shifting gaze frequently to their mothers" (p. 35).

In general, these studies suggest that deaf signing parents may be less focused on directing or attracting their child's attention, and more attentive to where the child is already looking and adjusting their own signing, when necessary, to place it within the child's field of vision or to comment on the target of the child's visual attention. For the acquisition of turn-taking and early turn-taking patterns between DHH signing adults and young DHH children, this indicates that turn-taking may be quite slow and characterized by sustained breaks in interaction while the adult waits on the child's attention before initiating the next turn. Deaf signing mothers may seek to provide targeted input and, in particular, are very careful to make sure that they have the child's attention before they sign, a finding reported across numerous studies of signing conversations with young deaf children. Meadow-Orlans et al. (2004) note that deaf mothers (in Dd dyads) were "highly consistent in providing linguistic information when children responded to an attention signal by looking at the mother" and that mothers' utterances were "highly responsive to their children's visual attention focus (or the focus just before they looked up at the mother)..." (p. 160). When compared directly to hearing-hearing mother-infant dyads, some studies have found that deaf-deaf signing mother-infant dyads are characterized by quantitatively less input (Harris et al., 1989, p. 93; Spencer and Lederberg, 1997, pp. 224–225; Meadow-Orlans et al., 2004). However, most of these studies also report that the deaf signing infants achieve similar linguistic milestones at similar ages to their hearing peers.

Reports of patient, watchful waiting from deaf signing caregivers contrast somewhat with studies that report on more explicit or overt efforts to get the attention of deaf signing children or to elicit signing from them. Pizer et al. (2011), for example, report frequent use of sign repetition and sign lengthening in deaf signing parent-child dyads (children observed at 9, 13, and 15 months). They suggest that this is a strategy intended to prompt or elicit a response from the child signer. Similarly, in a comparison of DHH and hearing parents of DHH children (18 months), Harris and Mohay (1997) reported that only mothers who were DHH regularly attempted to elicit their children's attention. As a result, these mothers had more frequent successful attention switches as well as failed attempts (p. 100–101).

Deaf or hard of hearing parents may vary considerably in their use of explicit strategies to manage and direct the visual attention of their signing children. This is likely also closely related to the social, physical, and cognitive development of the child. As Harris et al. (1989) point out, significant physical developmental milestones alter a child's mobility and ability to change their own focus of attention. Many longitudinal studies document the ways in which signing parents change their strategies in response to their child's changing capacities. This is reminiscent of the developmental milestones noted in Hilbrink et al. (2015) and Casillas et al. (2016), discussed

8 Three ASL parent–child dyads in the United States and three LSE parent–child dyads in Spain (Holzrichter, 2000).

in section "Acquiring turn-taking structures: Spoken language development". In these studies of hearing children acquiring spoken languages, researchers suggest that changes in turn timing may be tightly linked to changing social abilities. In these examples, turn timing and responsiveness slowed down for children as they reached various cognitive and social milestones. While DHH children who acquire a national sign language at home will proceed through the language acquisition process along a similar timeline to spoken language acquisition (Newport and Meier, 1985; Lillo-Martin and Henner, 2021), and with similar parallel cognitive and social developmental milestones, DHH children who acquire a sign language at school[9] enter this ecology at a much later stage of cognitive and social development, in addition to the differences between home and school social settings (Singleton and Morgan, 2006).

## Deaf or hard of hearing children acquiring a national sign language at school

We begin this section with a short vignette from a third-grade classroom at a state residential school for the deaf in the United States. Drawing on classroom observations from a longitudinal study, Ramsey and Padden (1998) provide several illustrative interactions between one student, Danny, who was a "newcomer" to this third-grade classroom, and his peers and teachers. At 9 years old, Danny was starting his second year at the school and the researchers observed that he had limited ASL proficiency and English literacy skills. They note that Danny was not only challenged by gaps in his ASL vocabulary and grammar, "Rather, Danny's apparent inattentiveness and his difficulties with writing also involved his inability to follow signed discourse in a classroom setting" (p. 16). They provide a more detailed example of the kinds of challenges Danny faced that relate explicitly to turn-taking in the classroom,

Connie (the teacher) directed the class's attention to a section on the worksheet listing the materials needed for the experiment. She opened the discussion with her WH-question pattern, signing "now," pointing to the appropriate section on her overhead, and asking what it said. . . Danny and a number of other students raised their hands. Before anyone was called on, however, Danny dropped his hand and began fingerspelling "materials" to himself. He looked down at the worksheet to confirm the spelling, and continued fingerspelling to himself as Connie pointed to another student, Larry, in the back of the room. As a result, Danny missed Connie's allocation of the turn to Larry, and when he looked around the room, could not locate him in time to see the answer (pp. 16–17).

The authors note that Danny loses track of the conversation, causing him to miss other students' turns as well as the teachers' instructions. Danny's missing skills in discourse were particularly noteworthy to the authors because of his advanced age, but his difficulties closely resemble many patterns observed for younger DHH children in signing preschool classrooms who come from hearing/speaking families.

There have been several studies of children who are acquiring a national sign language in classroom settings. As mentioned above, the majority of DHH students are not receiving consistent sign language input at home and thus depend on the language input that they are exposed to at school to acquire the national sign language. Many studies compare students who do receive sign language input at home (deaf of deaf, DD, DoD) to students who are from hearing families (deaf of hearing, DH, DoH). In the following sections, we discuss these studies, summarized in **Table 7**.

A diverse range of methodologies have been used to study classroom interactions, including longitudinal engagement with a single classroom (Ramsey and Padden, 1998; Lieberman, 2015), sampling from different activities and spaces in classrooms (Smith and Sutton-Spence, 2005; DeLuzio and Girolametto, 2006), and comparing different types of students or teachers across classrooms (Mather, 1987; Singleton and Crume, 2010). Researchers have also used combinations of video recorded data as well as interviews with deaf teachers to explore language ideologies operating in these classroom spaces (Singleton and Morgan, 2006; Graham and Tobin, 2020). These studies document the specific attentional strategies that teachers employ, the efficacy of these strategies, and their beliefs about student language development in the classroom.

While many DHH children are receiving their primary language input in the classroom, the classroom ecology is remarkably distinct from the home context described for DHH children learning a national sign language at home (Singleton and Morgan, 2006; Graham and Tobin, 2020). One signing adult teacher (and often one additional signing teaching assistant) is tasked with the management of three or more young children. DHH children are thus embedded in a social context in which there are many competing demands on their visual attention and in which the majority of their interactions will be multi-party and they must compete for the floor. They are learning to manage their own visual attention, switching between the teacher, visual materials, and other signing students (Mather and Clark, 2012). Additionally, children in classroom settings are physically, cognitively, and socially more developed than the DHH infant who first encounters national sign language at home from their parent. We discuss the implications of these factors further in section "Discussion."

9 This is only true for DHH children who are enrolled in schools that use sign language as the mode of instruction. Many DHH children are mainstreamed or enrolled in schools where the primary language of instruction is spoken language.

TABLE 7 Studies of taking turns and getting attention in signing classrooms.

| Study | Language(s) | N participants | Setting | Data |
|---|---|---|---|---|
| DeLuzio and Girolametto, 2006 | American Sign Language (ASL) | 4 children (3;3–4;7)<br>(2 DHH, 1 CODA, 1 hearing child with deaf grandparents)<br>1 deaf teacher | Bilingual/bicultural preschool classroom (Toronto) | Video recordings (30 min total: 15 min. dramatic play, 15 min. playdough)<br>-Type of attention strategy used by teacher<br>-Intent of attention strategy<br>-Child response |
| Graham and Tobin, 2020 | American Sign Language (ASL), French Sign Language (LSF), Japanese Sign Language (JSL) | | Signing kindergarten classrooms in the United States, Japan, and France | Video ethnography<br>Discussions of ideologies of sign language with deaf teachers |
| Lieberman, 2015 | American Sign Language (ASL) | 7 children (1;9–3;3) (all deaf of deaf native signers)<br>5 adults (2 assistants, both deaf; 3 hearing, signing) | Signing preschool classroom in residential school for the deaf (1) | Video recordings of free play activities (30 h over three months)<br>Strategies for getting attention (1,600 turns across all child participants; 477 peer initiations) |
| Mather, 1987 | American Sign Language (ASL) | 9 children in two classrooms (4 children deaf of deaf native signers)<br>2 teachers, 1 deaf native signer and 1 hearing signer | Signing preschool classrooms (2) | Video recording of story time<br>Annotated use of two types of eye gaze to manage turn taking |
| Ramsey and Padden, 1998 | American Sign Language (ASL) | 1 focal student, class of 12 DHH students<br>1 teacher (deaf native signer) | Third grade classroom, state residential school for the deaf | Video recordings (35 h total, 20 observation days) |
| Singleton and Crume, this issue | American Sign Language (ASL) | 6 children (all DHH) (3 children deaf of deaf native signers)<br>1 teacher, 1 aide (deaf, fluent signers) | Signing preschool classrooms (2) | Video recording of classroom activities<br>Attention actions and participant cues used by teachers |
| Singleton and Morgan, 2006 | American Sign Language (ASL) | 3 deaf teachers | Bilingual/bicultural preschool | Video recordings |
| Smith and Sutton-Spence, 2005 | British Sign Language (BSL) | 10 children (3–5 years old) (all DHH)<br>2 teachers (deaf adults, BSL signers) | Signing nursery school, children attend full or half days | Video recordings (12 sessions) during free play and lunch<br>Attention-getting strategies by teachers and children |

## Signing teachers and deaf or hard of hearing children

Conversations in classrooms diverge significantly from other social settings. In a pattern first identified by Mehan (1979), teachers frequently employ a structure known as Initiation – Response – Evaluation (or Feedback), or IRE. In this structure, the teacher poses a question (the initiation) for which they typically already have the answer, and solicit an answer from a single student or multiple students (the response), the teacher then provides an evaluation or feedback assessing the correctness of the student response. This structure has been widely documented in spoken language classrooms, including those with DHH children (Wood et al., 1982), but we know less about turn-taking patterns in signing classrooms with DHH students. Studies have documented the efforts of signing teachers in these classrooms to establish and direct the visual attention of students who are entering into the classroom conversation. As mentioned above, visual attention is a prerequisite for perceiving and, ultimately, entering into signed conversation turns. A signer not currently holding the floor, have visual access to (be looking at) the current signer, and, in the case of multi-party conversations, anticipate a change of turns and the location of the next signer so that they can shift their gaze to see the next turn. In this section we review some of the studies that have documented classroom discourse in early signing classrooms, focusing on this skill of shifting visual attention during sign conversation.

In contrast to the studies of DHH signing parents discussed in section "Deaf or Hard of Hearing Children Acquiring a National Sign Language at Home" that report that caregivers often used a strategy of waiting for their child's attention, many studies of classroom sign language socialization document explicit attention management strategies used by signing teachers. These strategies are numerous; in a study of a British nursery school, Smith and Sutton-Spence (2005) develop an inventory of 39 different strategies that teachers and children used to attract attention. These strategies often target students, like Danny, introduced above, who enter the signing classroom with less previous experience following and contributing to signed conversations.

In a study of a signing preschool classroom, Singleton and Crume (2010) found that a deaf teacher and her deaf teacher's aide directed many linguistic prompts toward the DHH students that signaled where to look (LOOK-AT-ME, READY?); however, the teachers used noticeably more physical/tactile prompts (tapping) toward the deaf children of hearing parents (DoH) who were not always anticipating where to look in the conversation. DoH students were also on the receiving end of "delay prompts" from the teacher in response to their repeated interruptions or trying to participate when it was clearly not their turn. The findings in this study suggest that by age 5, DoD appear to have internalized turn-taking patterns of ASL insofar as needing only linguistic cues like READY? from the teacher to signal where to look and also show low rates of interrupting the teacher. By contrast, DoH students still needed scaffolding to support their looking behavior and conversational participation.

In a similar study of teacher attention strategies in a signing preschool classroom in Toronto, DeLuzio and Girolametto (2006) evaluated how a deaf signing teacher used different types of attention strategies (tactile, visual, visual using an ASL sign, and observing/waiting) and whether these were used for different intents (initiating a conversation, continuing a conversation, or controlling a child's behavior). They also evaluated the outcome of these attention strategies, finding that the teacher was most likely to use either tactile (tapping) or visual (waving) strategies, particularly when trying to gain students' attention to initiate a conversation. The teacher did not often make attempts to continue or regain students' attention in ongoing conversation, suggesting that many interactions were brief. In terms of the success of the four types of attention strategies, waiting was significantly less successful than any of the remaining three strategies (tactile, visual, and visual using an ASL sign). This finding is somewhat counterintuitive, given the extensive literature (discussed above in section "Deaf or Hard of Hearing Children Acquiring a National Sign Language at Home") on patterns of interaction and turn taking between deaf caregivers and deaf infants and children.

In addition to manual strategies for managing attention, some studies have documented non-manual techniques that teachers use to manage student attention. In a study of two signing classrooms, Mather (1987) compares the use of different gaze strategies during a shared storybook activity by a deaf and a hearing teacher. Mather notes significant differences in the quality of turn taking in the two classrooms. She attributes these differences to the use of two types of gaze that indicate whether a question or comment is being directed to an individual student (I-GAZE) or to the entire group (G-GAZE). Mather suggests that the hearing teacher lacked proficient control of the two types of gaze to regulate turn taking in her signing and this led to confusion and misunderstandings with her students (p. 19).

Whether teachers are using manual or non-manual cues like eye gaze, the visual and conversational demands on students in the signing classroom setting are high. Studies from Smith and Sutton-Spence (2005), Singleton and Crume (this issue), and DeLuzio and Girolametto (2006) suggest that teachers do a lot of work to manage students' attention to classroom discourse and to scaffold students' attention so that they can follow and enter into the classroom conversation. Mather raises the additional consideration that some teachers may lack the signing proficiency to provide this scaffolding.

Beyond the individual strategies and cues that teachers employ, other studies have highlighted the significant role of deaf signing teachers, to provide more naturalistic interactions for deaf signing students than might normally happen in a classroom setting. In their comparative study of deaf signing preschools in the United States, France, and Japan, Graham and Tobin (2020) argue that deaf teachers are essential agents in the socialization of deaf children, not only in the acquisition of sign languages, but also of Deaf cultural norms of "eye gaze, attention elicitation strategies, joint attention, facial expressions, and body language" (p. 147) or what they describe as "deaf ways of being" (p. 147). Similarly, Singleton and Morgan (2006) highlight the role of deaf teachers in signing classrooms, who can offer students explicit reflections on the experience of being deaf and how to interact effectively with hearing people (p. 359). In terms of turn-taking, deaf teachers may be more attuned to novice child signers' needs and can make the social practices and expectations that underlie successful sign conversations more explicit for students (Graham and Tobin, 2020, pp. 152–154). As Graham and Tobin note, "Teachers who have all five senses may not understand what it is like to only have four senses and how those individuals with four senses compensate in terms of enhanced communication information" (p. 158).

## Signing with deaf or hard of hearing child peers

While many studies of adult-child conversations (both sign and speech) note that adults often scaffold interactions for the child participant, sometimes peer conversations between children do not proceed as smoothly. As noted in section "Acquiring turn-taking structures: Spoken language development", for example, turn gaps between child peers at ages 2–4 were significantly longer than adult turn gaps (Garvey and Berninger, 1981). In a study of deaf children of deaf parents, Lieberman (2015) reports that by 19 months of age native signing deaf children are aware that they need to establish eye gaze before beginning a turn. Children very rarely proceeded with a turn if they did not have the visual attention of their conversational partner, but child signers also frequently "gave up and either walked away or made no further attempts to get the addressee's attention" (p. 862). In terms of the success or failure of initiations, children had a similar success rate in their initiations with peers (64% successful) as they did with their teachers (65% successful). Notably, this success rate between deaf conversation partners is much higher than that reported for deaf children interacting with hearing children (Messenheimer-Young and Kretschmer, 1994; Deluzio and Girolametto, 2011).

In the Lieberman (2015) study, children had various strategies for attracting and maintaining the visual attention of their peer interlocutor including taps, object use, signs, actions, and physical approach. Even though waves are a very common strategy in adult signing conversations, children rarely used them in peer interactions (p. 861). To manage turns, children were strategic in their use of different techniques. If they were initiating a turn they were more likely to use taps or waves, but if their conversational peer was already attending they tended to use signs or gestures to sustain attention. These results suggest that, even from a very young age (19 months), DHH children who receive early sign language input acquire important turn-taking skills – like waiting for the visual attention of their interlocutor – and strategies – like tapping or signing to attract and sustain attention. To our knowledge, no studies have explored turn timing in these contexts, but it would be interesting to know how often these turns overlapped, or whether the gaps between turns were slower compared to adult signers (as has was found for spoken language interactions between hearing children at the same ages).

In general, there are few studies exploring the impact of late language acquisition, or language deprivation (Hall, 2017; Hall et al., 2019) on the development of pragmatic skills in signing DHH children. A recent overview study suggests that DHH children acquiring *spoken* languages show significant delays in pragmatic skills (Paatsch and Toe, 2014; Paul et al., 2020), but less is known about DHH children acquiring sign languages. In their discussion of language deprivation, Koulidobrova and Chen-Pichler (2021) advocate for a reconsideration of the systems developed by DHH children who do not receive early sign language input. They suggest that researchers take seriously the systems that DHH children develop in the absence of full input, which they describe as the "initial system." It would be worthwhile for studies of these "initial systems" to document turn-taking and other pragmatic skills in addition to lexical and syntactic patterns.

For other domains of linguistic development, it is clear that early ASL exposure (before 6 months) can lead to native-like results, even for DHH children who are in hearing families [see Caselli et al. (2021) on vocabulary acquisition and Henner et al., 2016 for syntax]. In contrast, delayed sign language exposure may contribute to a range of language disfluencies in sign language comprehension and production, including in syntax (Boudreault and Mayberry, 2006), morphology, and processing (Mayberry, 2010). The relationship between sign language input and experience and pragmatic skills should be explored in future studies, a point we return to in section "Discussion" below.

## Deaf or hard of hearing children acquiring a local sign language at home

Deaf or hard of hearing children born into hearing families in countries with a national sign language enter communities with specific beliefs about appropriate and necessary interventions. In other countries the national sign language may not be as widely used, medical interventions may be less common, affordable, or accessible, and schools for the deaf may be geographically or financially inaccessible to DHH children. Without early hearing screenings, many families may not know that their child is deaf until much later, sometimes 6 or 7 years old. In this context, DHH children and adults often develop and use local sign languages to communicate with hearing relatives and friends. As mentioned in the introduction, there is immense variation in these systems, in terms of how many signers they have, the geographic spread of their use, and hearing people's attitudes toward deaf people and signing. In this section, we consider implications for development of turn taking in sign language conversations for children in these settings. While extensive work has documented the lexical, morphological, and syntactic properties of many of these languages, fewer studies have focused on pragmatic practices like turn taking. We discuss studies that have described turn-taking in local sign languages used in Central and South America, as well as areas for future study.

Haviland (2020) provides a close analysis of several conversations between three deaf adult siblings in Chiapas, Mexico. In his description of "Z sign," Haviland highlights the significant role of eye gaze in these exchanges, noting the ways that gaze direction is mobilized for referential and indexical purposes, as well as selection of the next participant in the conversation. Gaze can be used to designate the next signer, or to establish someone as an addressee. Haviland observes that gaze can also be withheld to exclude or disallow participation from a potential interlocutor. Similarly, in a study of sign language interactions in a classroom setting in Iquitos, Peru, Goico (2020) describes the use of eye gaze – and the withholding of gaze – to manage turns in conversations between deaf and hearing students who sign with each other regularly at school. In both of these examples, local sign languages are used between skilled deaf and hearing signers and, similar to discussions of turn initiations in national sign languages like ASL, signers typically establish eye gaze with their interlocutor before initiating a turn.

In a comparative study of child sign socialization from three communities, including "Z" as well as signers from the village of San Juan Quiahije, in Oaxaca, Mexico, and the town of Nebaj, in Guatemala, Hou et al. (2021), describe patterns of attention-getting, turn-taking, and physical orientation in conversations between children and adults in local sign languages. In these three sign language communities, gaze serves as a significant regulator for turn-taking. Adult signers establish eye gaze with their interlocutor before they begin signing, and in San Juan Quiahije and Nebaj, adult signers used waves, taps, and knocking on a table surface, prior to beginning their turns. Beyond the use of similar signals to initiate turns, however, Horton et al. find differences in the degree to which adult signers engage child signers directly in conversation. The authors argue that this variation may be influenced by local cultural practices where children tend to learn through observation rather than be explicitly socialized through child-directed language patterns.

While this body of work on emerging sign languages is still developing, we hope that going forward these researchers will go beyond single signer informants and collect video-recordings of caregiver-child dyads and multi-party conversations as well to explore conversational and pragmatic practices in signed languages. In many of these communities, multi-party interactions are more common for children to experience because several families can live together within a compound, or children are cared for by extended family networks or older siblings. It will be especially interesting to note the timing of turns and whether overlaps are more likely to exist in young sign languages.

## Discussion

In this article we have reviewed studies that explore the relationship between language modality and turn-taking, the trajectory of turn-taking skills in infancy and childhood, as well as the development of turn-taking in diverse social ecologies for sign language acquisition. This work sets up several puzzles, as well as areas for future investigation. In terms of the relationship between language modality and turn-taking, by some measures, turn-timing in sign languages closely patterns with that of spoken languages for particular turn types (polar question and answer sequences). Further, conversations in sign and speech seem to be generally guided by the same underlying principle of minimizing overlaps as well as gaps between turns, lending support for a universal "interaction engine" (Levinson, 2019). However, studies that have attempted to measure turn timing highlight the challenge of identifying sign boundaries. It remains somewhat unclear whether sign language conversations have comparatively more overlap of turns or if overlapping turns may last longer, on average, than spoken language turns. We do not know what turn timing looks like for DHH infants and children in interactions with their caregivers. This would provide a useful datapoint to understand the time course of turn-taking development in sign language acquisition.

For the acquisition of turn-taking in childhood, unlike other domains of language use, children seem to have the ability and desire to engage in turn-taking activities and behaviors from a very young age. As they develop, there is some evidence that increasing linguistic and social skills may slow down their prelinguistic alternations with caregivers. Thus, even though some of this ability appears quite early, its time course is actually quite protracted and interacts with other developmental milestones (Casillas et al., 2016).

The early availability of turn-taking behaviors has implications for DHH children acquiring a sign language at older stages of development. Particularly in combination with evidence that some pragmatic cues for turn-taking in sign languages appear to be available to hearing adults with co-speech gesture experience but no sign language experience (de Vos et al., 2022). These two pieces of evidence might suggest that DHH signing children would have intuitions about pragmatics and turn-taking in sign language, even if they enter the signing classroom with minimal sign language experience from home. Hypothetically, they should be able to draw on innate, early abilities and/or cues that are available to all language users. But we do not see this pattern in much of the data from classrooms where children are acquiring sign languages. The DHH children who enter the signing classroom with appropriate turn-taking abilities and pragmatic skills typically have sign exposure early in their home environment. Given the fact that many late learners of sign languages do not appear to have natural instincts for visual attention that will grant them access to signed interactions in the classroom, we review literature that discusses teacher practices.

If the classroom environment is the primary site of sign language socialization for DHH children from hearing families who do not sign, one strategy might be for teachers to emulate DHH signing parents. Based on the literature documenting deaf signing caregivers' practices, this entails creating an immersive signing environment in which the adult signer waits for the novice signer's visual attention or adapts their signing to be within the novice signer's visual field. In the classroom, this

TABLE 8 Differences in the social ecologies of home and school as primary sites of sign language acquisition.

| | National sign language acquisition in deaf signing families | National sign language acquisition in the classroom | Local sign language acquisition in signing families |
|---|---|---|---|
| Participant framework | Dyadic | Multiparty | Multiparty |
| Contexts of use | Home (informal) | School (institutional) | Home (informal) |
| Age of acquisition | Younger (from birth) | Older (school-age) | Variable |
| Style of interaction | Socializing | Didactic/instructional | Socializing |

might involve waiting for DHH students to notice or develop their visual monitoring skills without explicit prompts or scaffolding. This is not, however, what studies have found is the predominant pattern in signing classrooms. Teachers appear to often use very explicit socializing strategies, though this may vary significantly based on the activity. In a recent study of shared story-time in kindergarten and first grade classrooms, Hou et al. (2021) found that signing teachers were less likely to explicitly direct students' attention than speaking teachers in oral classrooms with DHH students who were using spoken English. There are a number of significant differences between the home environment for young DHH signers who have DHH signing parents and DHH children from hearing families at school, some of these are summarized in **Table 8**.

As discussed across several sections, the social demands and affordances of these three diverse settings for acquisition have significant implications for the development of turn-taking skills. While national sign language acquisition that occurs in deaf families at home may be characterized by less input that is very targeted to the individual child, this may not be feasible in a classroom setting. Further, the DHH child is immersed in sign language and visual-manual turn-taking activities from early in development and in interactions that are primarily about socialization. Before the DHH child is fully mobile and prior to their acquisition of linguistic skills, they can be the recipient of targeted input that is adapted to their attentional abilities. National sign language acquisition in the signing classroom happens for DHH children who are already mobile and who are already part of families that are using speech and auditory cues for turn-taking. Thus, they are getting less sign language input in a context in which there is significantly more competition – both for their visual attention and for the conversational signing floor – as they are typically engaged in multiparty interactions with both their peers and their teacher. We still lack significant information about how turn-taking transpires in multiparty adult signing conversations, but in classrooms, many teachers seem to focus on managing turns so that students do not overlap with one another, and on supporting DHH students who are struggling to figure out where to direct their attention (Singleton and Crume, 2010). The acquisition of local sign languages at home provides an interesting counterpoint to the national sign language examples. Similar to national sign language acquisition at home, the signing in these contexts may not be overly marked for the child, depending on ideologies of language socialization in the signing community. Child signers may need to learn to develop their turn-taking and visual attention skills with minimal explicit instruction or guidance. Similar to national sign language acquisition in the classroom, however, children acquiring local sign languages may typically be observers of multiparty signed conversations, rather than participants.

Deaf or hard of hearing children acquire sign languages in highly variable contexts, making it difficult to isolate the relative contributions of language modality, linguistic and cognitive development, and social setting, to any language practice. By gathering more thorough data from naturalistic interactions across these ecologies, we will be better able to piece together the emergence of turn-taking skills in sign language development, and interrogate the relationship between modality and turn-taking in conversation.

## Author contributions

Both authors listed have made a substantial, direct, and intellectual contribution to the work, and approved it for publication.

## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Publisher's note



## References

Ali, F., Ali, K., and Braithwatie, B. (2021). "Intralinguistic and cross-linguistic variation in the turn-taking organization between deaf-blind signers: new evidence from Bay Islands Sign Language," in *Paper Presentation at the New Ways of Analyzing Variation (NWAV 49) Conference. October 19-24, 2021*, (Austin, TX).

Arora, S., Smolen, E. R., Wang, Y., Hartman, M., Howerton-Fox, A., and Rufsvold, R. (2020). Language environments and spoken language development of children with hearing loss. *J. Deaf Stud. Deaf Educ.* 25, 457–468. doi: 10.1093/deafed/enaa018

Baker, C. (1977). "Regulators and turn-taking in american sign language discourse," in *On the Other Hand: New Perspectives on American Sign Language*, ed. L. Friedman (New York, NY: Academic Press), 215–236.

Bates, E. (1976). *Language and Context*. New York, NY: Academic Press.

Bögels, S., and Torreira, F. (2015). Listeners use intonational phrase boundaries to project turn ends in spoken interaction. *J. Phonet.* 52, 46–57. doi: 10.1016/j.wocn.2015.04.004

Bolden, G. B. (2003). Multiple modalities in collaborative turn sequences. *Gesture* 3, 187–212. doi: 10.1075/gest.3.2.04bol

Boudreault, P., and Mayberry, R. (2006). Grammatical processing in American Sign Language: age of first-language acquisition effects in relation to syntactic structure. *Lang. Cogn. Process.* 21, 608–635. doi: 10.1080/01690960500139363

Caselli, N., Pyers, J., and Lieberman, A. M. (2021). Deaf children of hearing parents have age-level vocabulary growth when exposed to American Sign Language by 6 months of age. *J. Pediatr.* 232, 229–236. doi: 10.1016/j.jpeds.2021.01.029

Casillas, M., and Frank, M. C. (2017). The development of children's ability to track and predict turn structure in conversation. *J. Mem. Lang.* 92, 234–253. doi: 10.1016/j.jml.2016.06.013

Casillas, M., Bobb, S. C., and Clark, E. V. (2016). Turn-taking, timing, and planning in early language acquisition. *J. Child Lang.* 43, 1310–1337. doi: 10.1017/S0305000915000689

Caspers, J. (2003). Local speech melody as a limiting factor in the turn-taking system in Dutch. *J. Phonet.* 31, 251–276. doi: 10.1016/S0095-4470(03)00007-X

Cibulka, P. (2016). On how to do things with holds: manual movement phases as part of interactional practices in signed conversation. *Sign Lang. Stud.* 16, 447–472. doi: 10.1353/sls.2016.0015

Coates, J., and Sutton-Spence, R. (2001). Turn-taking patterns in deaf conversation. *J. Sociolinguist.* 5, 507–529. doi: 10.1111/1467-9481.00162

Couper-Kuhlen, E., and Selting, M. (1996). "Towards an interactional perspective on prosody and a prosodic perspective on interaction," in *Prosody in Conversation*, eds E. Couper-Kuhlen and M. Selting (Cambridge: Cambridge University Press), 11–56. doi: 10.1017/CBO9780511597862.003

De Ruiter, J. P., Mitterer, H., and Enfield, N. J. (2006). Projecting the end of a speaker's turn: a cognitive cornerstone of conversation. *Language* 82, 515–535. doi: 10.1353/lan.2006.0130

de Vos, C., Casillas, M., Uittenbogert, T., Crasborn, O., and Levinson, S. C. (2022). Predicting conversational turns: signers' and non-signers' sensitivity to language-specific and globally accessible cues. *Language* 98, 35–62. doi: 10.1353/lan.2021.0085

de Vos, C., Torreira, F., and Levinson, S. C. (2015). Turn-timing in signed conversations: coordinating stroke-to-stroke turn boundaries. *Front. Psychol.* 6:268. doi: 10.3389/fpsyg.2015.00268

DeLuzio, J., and Girolametto, L. (2006). Joint attention strategies used by a preschool educator who is deaf. *J. Deaf Stud. Deaf Educ.* 11, 214–223. doi: 10.1093/deafed/enj022

Deluzio, J., and Girolametto, L. (2011). Peer interactions of preschool children with and without hearing loss. *J. Speech Lang. Hear. Res.* 54, 1197–1210. doi: 10.1044/1092-4388(2010/10-0099)

Dingemanse, M., Roberts, S. G., Baranova, J., Blythe, J., Drew, P., Floyd, S., et al. (2015). Universal principles in the repair of communication problems. *PLoS One* 10:e0136100. doi: 10.1371/journal.pone.0136100

Duncan, M. K., and Lederberg, A. R. (2018). Relations between teacher talk characteristics and child language in spoken-language deaf and hard-of-hearing classrooms. *J. Speech Lang. Hear. Res.* 61, 2977–2995. doi: 10.1044/2018_JSLHR-L-17-0475

Duncan, S. (1972). Some signals and rules for taking speaking turns in conversations. *J. Pers. Soc. Psychol.* 23, 283–292. doi: 10.1037/h0033031

Duncan, S., and Fiske, D. W. (1977). *Face-to-Face Interaction: Research, Methods, and Theory*, 1st Edn. Milton Park: Routledge, doi: 10.4324/9781315660998

Ervin-Tripp, S. (1979). "Children's verbal turn-taking," in *Developmental Pragmatics*, eds E. Ochs and B. B. Scheiffelin (New York, NY: Academic Press), 391–414.

Ford, C., and Thompson, S. (1996). "Interactional units in conversation: syntactic, intonational, and pragmatic resources for the management of turns," in *Interaction and Grammar*, eds E. Ochs, E. Schegloff, and S. Thompson (Cambridge: Cambridge University Press), 134–184. doi: 10.1017/CBO9780511620874.003

Garrod, S., and Pickering, M. J. (2015). The use of content and timing to predict turn transitions. *Front. Psychol.* 6:751. doi: 10.3389/fpsyg.2015.00751

Garvey, C., and Berninger, G. (1981). Timing and turn taking in children's conversations. *Discourse Process* 4, 27–57. doi: 10.1080/01638538109544505

Girard-Groeber, S. (2015). The management of turn transition in signed interaction through the lens of overlaps. *Front. Psychol.* 6:741. doi: 10.3389/fpsyg.2015.00741

Goico, S. A. (2020). A linguistic ethnography approach to the study of deaf youth and local signs in Iquitos, Peru. *Sign Lang. Stud.* 20, 619–643. doi: 10.1353/sls.2020.0021

Goodwin, C. (1981). *Conversational Organization: Interaction Between Speakers and Hearers*. New York, NY: Academic Press.

Graham, P. J., and Tobin, J. J. (2020). "The body as a canvas: developing a Deaf bodily habitus in deaf signing preschools," in *Deaf Identities: Exploring New Frontiers*, eds I. Leigh and C. O'Brien (Oxford: Oxford University Press), 145–161. doi: 10.1093/oso/9780190887599.003.0007

Gratier, M., Devouche, E., Guellai, B., Infanti, R., Yilmaz, E., and Parlato-Oliveira, E. (2015). Early development of turn-taking in vocal interaction between mothers and infants. *Front. Psychol.* 6:1167. doi: 10.3389/fpsyg.2015.01167

Groeber, S., and Pochon-Berger, E. (2014). Turns and turn-taking in sign language interaction: a study of turn-final holds. *J. Pragmat.* 65, 121–136. doi: 10.1016/j.pragma.2013.08.012

Hall, M. L., Hall, W. C., and Caselli, N. K. (2019). Deaf children need language, not (just) speech. *First Lang.* 39, 367–395. doi: 10.1177/0142723719834102

Hall, W. C. (2017). What you don't know can hurt you: the risk of language deprivation by impairing sign language development in deaf children. *Matern. Child Health J.* 21, 961–965. doi: 10.1007/s10995-017-2287-y

Harris, M., and Mohay, H. (1997). Learning to look in the right place: a comparison of attentional behavior in deaf children with deaf and hearing mothers. *J. Deaf Stud. Deaf Educ.* 2, 95–103. doi: 10.1093/oxfordjournals.deafed.a014316

Harris, M., Clibbens, J., Chasin, J., and Tibbitts, R. (1989). The social context of early sign language development. *First Lang.* 9, 81–97. doi: 10.1177/014272378900902507

Haviland, J. B. (2020). "Signs, interaction, coordination, and gaze: interactive foundations of "Z"—an emerging (sign) language from Chiapas, Mexico," in *Emerging Sign Languages of the Americas*, eds M. Coppola, O. Le Guen, and J. Safar (Berlin: De Gruyter Mouton), 35–96. doi: 10.1515/9781501504884-002

Heldner, M. (2011). Detection thresholds for gaps, overlaps, and no-gap-no-overlaps. *J. Acoust. Soc. Am.* 43, 508–513. doi: 10.1121/1.3598457

Henner, J., Caldwell-Harris, C. L., Novogrodsky, R., and Hoffmeister, R. (2016). American Sign Language syntax and analogical reasoning skills are influenced by early acquisition and age of entry to signing schools for the deaf. *Front. Psychol.* 7:1982. doi: 10.3389/fpsyg.2016.01982

Hilbrink, E. E., Gattis, M., and Levinson, S. C. (2015). Early developmental changes in the timing of turn-taking: a longitudinal study of mother–infant interaction. *Front. Psychol.* 6:1492. doi: 10.3389/fpsyg.2015.01492

Holzrichter, A. (2000). *A Crosslinguistic Study of Child-Directed Signing: American Sign Language and Sign Language of Spain*. Unpublished PhD Dissertation. Austin, TX: University of Texas.

Hou, L., Horton, L., German, A., and Singleton, J. (2021). "Sign language socialization in three indigenous Mesoamerican communities: A qualitative comparative study," in *Poster Presented at the Boston University conference on language development*, Boston, MA.

Horton, L., Lederberg, A., and Singleton, J. (2022). "Visual attention management during book reading activities with deaf and hard of hearing students," in *Paper Presentation at the Annual Meeting of the American Educational Research Association (AERA)*, (San Diego, CA).

Hou, L., and de Vos, C. (2022). Classifications and typologies: labeling sign languages and signing communities. *J. Sociolinguist.* 26, 118–125. doi: 10.1111/josl.12490

Jefferson, G. (1984). Notes on a systematic deployment of the acknowledgement tokens "yeah"; and "mm hm". *Paper Linguist.* 17, 197–216. doi: 10.1080/08351818409389201

Jefferson, G. (1986). Notes on 'latency' in overlap onset. *Hum. Stud.* 9, 153–183. doi: 10.1007/BF00148125

Kendon, A. (1967). Some functions of gaze-direction in social interaction. *Acta Psychol.* 26, 22–63. doi: 10.1016/0001-6918(67)90005-4

Kendon, A. (1972). "Some relationships between body motion and speech: an analysis of an example," in *Studies in Dyadic Communication*, eds A. W. Siegman and B. Pope (New York, NY: Pergamon Press), 177–210. doi: 10.1016/B978-0-08-015867-9.50013-7

Kendon, A. (1980). A description of a deaf-mute sign language from the Enga Province of Papua New Guinea with some comparative discussion Part III: aspects of utterance construction. *Semiotica* 32, 245–314. doi: 10.1515/semi.1980.32.3-4.245

Kendon, A. (2004). "Gesticulation and speech: two aspects of the process of utterance," in *Nonverbal Communication and Language*, ed. M. R. Key (The Hague: Mouton de Gruyter), 207–227. doi: 10.1515/9783110813098.207

Kita, S., van Gijnm, I., and van der Hulst, H. (1998). "Movement phases in signs and co-speech gestures, and their transcription by human coders," in *Gesture and Sign Language in Human-Computer Interaction*, eds I. Wachsmuth and M. Fröhlich (London: Springer-Verlag), 23–35. doi: 10.1007/BFb0052986

Koulidobrova, E., and Chen-Pichler, D. (2021). Cripping the "Delay": multilingualism-related consequences of re-labeling language deprivation systems. *Front. Commun.* 6:751457. doi: 10.3389/fcomm.2021.751457

Kusters, A., O'Brien, D., and de Meulder, M. (2017). "Innovations in deaf studies: critically mapping the field," in *Innovations in Deaf Studies: The Role of Deaf Scholars*, eds A. Kusters, M. de Meulder, and D. O'Brien (Oxford: Oxford University Press), 1–53.

Lederberg, A. R., and Everhart, V. S. (2000). Conversations between deaf children and their hearing mothers: pragmatic and dialogic characteristics. *J. Deaf Stud. Deaf Educ.* 5, 303–322. doi: 10.1093/deafed/5.4.303

Levinson, S. C. (2006). "On the human "interaction engine," in *Roots of Human Sociality. Culture, Cognition and Interaction*, eds N. J. Enfield and S. C. Levinson (New York, NY: Berg), 39–69. doi: 10.4324/9781003135517-3

Levinson, S. C. (2016). Turn-taking in human communication–origins and implications for language processing. *Trends Cogn. Sci.* 20, 6–14. doi: 10.1016/j.tics.2015.10.010

Levinson, S. C. (2019). "Interactional foundations of language: the interaction engine hypothesis," in *Human Language: From Genes and Brain to Behavior*, ed. P. Hagoort (Boston: MIT Press), 189–200.

Levinson, S. C., and Torreira, F. (2015). Timing in turn-taking and its implications for processing models of language. *Front. Psychol.* 6:731. doi: 10.3389/fpsyg.2015.00731

Lieberman, A. M. (2015). Attention-getting skills of deaf children using American Sign Language in a preschool classroom. *Appl. Psycholinguist.* 36, 855–873. doi: 10.1017/S0142716413000532

Lillo-Martin, D., and Henner, J. (2021). Acquisition of sign languages. *Annu. Rev. Linguist.* 7, 395–419. doi: 10.1146/annurev-linguistics-043020-092357

Lloyd, J., Lieven, E., and Arnold, P. (2001). Oral conversations between hearing-impaired children and their normally hearing peers and teachers. *First Lang.* 21, 83–107. doi: 10.1177/014272370102106104

Local, J., and Kelly, J. (1986). Projection and 'silences' : notes on phonetic and conversational structure. *Hum. Stud.* 9, 185–204. doi: 10.1007/BF00148126

Manrique, E., and Enfield, N. (2015). Suspending the next turn as a form of repair initiation: Evidence from Argentine Sign Language. *Front. Psychol.* 6:1326. doi: 10.3389/fpsyg.2015.01326

Mather, S. (1996). "Initiation in visually constructed dialogue: reading books to three- to eight- year-old students who are deaf and hard-of-hearing," in *Multicultural Aspects of Sociolinguistics in Deaf Communities*, ed. C. Lucas (Washington, D.C: Gallaudet University Press), 109–131.

Mather, S. A. (1987). Eye gaze & communication in a deaf classroom. *Sign Lang. Stud.* 54, 11–30. doi: 10.1353/sls.1987.0008

Mather, S. M., and Clark, M. D. (2012). An issue of learning: the effect of visual split attention in classes for deaf and hard of hearing students. *Odyssey N. Direct. Deaf Educ.* 13, 20–24.

Mauldin, L. (2016). *Made to Hear: Cochlear Implants and Raising Deaf Children*. Minneapolis, MIN:University of Minnesota Press. doi: 10.5749/minnesota/9780816697243.001.0001

Mayberry, R. I. (2010). "Early language acquisition and adult language ability: what sign language reveals about the critical period," in *The Oxford Handbook of Deaf Studies, Language, and Education*, Vol. 2, eds M. Marschark and P. Spencer (Oxford: Oxford University Press), 281–291. doi: 10.1093/oxfordhb/9780195390032.013.0019

Maynard, D. W. (1989). Perspective-display sequences in conversation. *Western J. Speech Commun.* 53, 91–113. doi: 10.1080/10570318909374294

McCleary, L., and de Arantes Leite, T. (2013). Turn-taking in Brazilian sign language: evidence from overlap. *J. Interact. Res. Commun. Disord.* 4:123. doi: 10.1558/jircd.v4i1.123

McIlvenny, P. (1995). "Seeing conversations: analysing sign language talk," in *Situated Order: Studies in the Social Organisation of Talk and Embodied Activities*, eds S. E. Clayman, D. W. Maynard, P. ten Have, and G. Psathas (Lanham, MD: University Press of America), 129–150.

Meadow-Orlans, K. P., Spencer, P. E., and Koester, L. S. (2004). *The World of Deaf Infants: A Longitudinal Study. Perspectives on Deafness*. Oxford: Oxford University Press. doi: 10.1093/acprof:oso/9780195147902.001.0001

Mehan, H. (1979). What time is it, Denise?': asking known information questions in classroom discourse. *Theory Pract.* 18, 285–294. doi: 10.1080/00405847909542846

Mesch, J. (2002). *Tactile sign language (Signum Verlag): Turn taking and questions in signed conversations of deaf-blind people*. Washington DC: Gallaudet University Press.

Messenheimer-Young, T., and Kretschmer, R. (1994). Can I Play?" A hearing-impaired preschooler's requests to access maintained social interaction. *Volta Rev.* 96, 5–18.

Mitchell, R. E., and Karchmer, M. (2004). Chasing the mythical ten percent: parental hearing status of deaf and hard of hearing students in the United States. *Sign Lang. Stud.* 4, 138–163. doi: 10.1353/sls.2004.0005

Mondada, L. (2019). Contemporary issues in conversation analysis: embodiment and materiality, multimodality and multisensoriality in social interaction. *J. Pragmat.* 145, 47–62. doi: 10.1016/j.pragma.2019.01.016

Newport, E. L., and Meier, R. P. (1985). "The acquisition of american sign language," in *The Cross-Linguistic Study of Language Acquisition*, ed. D. Slobin (New York, NY: Psychology Press), 881–938. doi: 10.4324/9781315802541-12

Ochs, E., and Schieffelin, B. B. (1979). *Developmenal Pragmatics*. New York, NY: Academic Press.

Paatsch, L. E., and Toe, D. M. (2014). A comparison of pragmatic abilities of children who are deaf or hard of hearing and their hearing peers. *J. Deaf Stud. Deaf Educ.* 19, 1–19. doi: 10.1093/deafed/ent030

Paul, R., Paatsch, L., Caselli, N., Garberoglio, C. L., Goldin-Meadow, S., and Lederberg, A. (2020). Current research in pragmatic language use among deaf and hard of hearing children. *Pediatrics* 146(Suppl._3), S237–S245. doi: 10.1542/peds.2020-0242C

Pizer, G., Meier, R. P., and Shaw Points, K. (2011). Child-directed signing as a linguistic register. *Formational Units Sign Lang.* 3:65.

Pudans-Smith, K. K., Cue, K. R., Wolsey, J. A., and Clark, M. D. (2019). To deaf or not to deaf: that is the question. *Psychology* 10, 2091–2114. doi: 10.4236/psych.2019.1015135

Ramsey, C., and Padden, C. (1998). Natives and newcomers: gaining access to literacy in a classroom for deaf children. *Anthropol. Educ. Q.* 29, 5–24. doi: 10.1525/aeq.1998.29.1.5

Rossano, F. (2013). "Gaze in Conversation," in *The Handbook of Conversation Analysis*, eds J. Sidnell and T. Stivers (Oxford: Blackwell), 308–329. doi: 10.1002/9781118325001.ch15

Sacks, H., Schegloff, E. A., and Jefferson, G. (1974). "A simplest systematics for the organization of turn taking for conversation," in *Studies in the organization of conversational interaction*, ed. J. Schenkein (New York, NY: Academic Press), 7–55. doi: 10.1016/B978-0-12-623550-0.50008-2

Schegloff, E. A. (1987). Analyzing single episodes of interaction: an exercise in conversation analysis. *Soc. Psychol. Quarterly* 50, 101–114. doi: 10.2307/2786745

Schegloff, E. A. (2000). Overlapping talk and the organization of turn-taking for conversation. *Lang. Soc.* 29, 1–63. doi: 10.1017/S0047404500001019

Schegloff, E. A. (2016). "Increments," in *Accountability in Social Interaction*, ed. J. Robinson (Oxford: Oxford University Press), 239–263. doi: 10.1093/acprof:oso/9780190210557.003.0008

Selting, M. (1996). On the interplay of syntax and prosody in the constitution of turn-constructional units and turns in conversation. *Pragmatics* 6, 371–388. doi: 10.1075/prag.6.3.06sel

Singleton, J. L., and Crume, P. (2010). "Socializing visual engagement in early childhood deaf education," in *Poster Presented at the International Congress of Education of the Deaf*, (Vancouver, BC).

Singleton, J. L., and Morgan, D. D. (2006). "Natural signed language acquisition within the social context of the classroom," in *Advances in the Sign Language Development of Deaf Children*, eds B. Schick, M. Marschark, and P. Spencer (Oxford: Oxford University Press), 344–375. doi: 10.1093/acprof:oso/9780195180947.003.0014

Smith, S., and Sutton-Spence, R. (2005). Adult–child interaction in a BSL nursery—getting their attention! *Sign Lang. Linguist.* 8, 131–152. doi: 10.1075/sll.8.1.07smi

Smolen, E. R., Wang, Y., Hartman, M. C., and Lee, Y. S. (2021). Effects of parents' mealtime conversation techniques for preschool children with hearing loss who use listening and spoken language. *J. Speech Lang. Hear. Res.* 64, 979–992. doi: 10.1044/2020_JSLHR-20-00420

Snow, C. E. (1977). The development of conversation between mothers and babies. *J. Child Lang.* 4, 1–22. doi: 10.1017/S0305000900000453

Snow, C. E., and Fergueson, C. A. (1977). *Talking to Children*. Cambridge: Cambridge University Press.

Spencer, P. E., and Lederberg, A. R. (1997). "Different modes, different models: communication and language of young deaf children and their mothers," in *Communication and Language Acquisition: Discoveries from Atypical Development*, eds C. B. Mervis, J. Bertrand, L. B. Adamson, and M. Romski (Baltimore, MD: Brookes), 203–230.

Spencer, P. E., Bodner-Johnson, B. A., and Gutfreund, M. K. (1992). Interacting with infants with a hearing loss: what can we learn from mothers who are deaf? *J. Early Interv.* 16, 64–78. doi: 10.1177/105381519201600106

Stivers, T., Enfield, N. J., Brown, P., Englert, C., Hayashi, M., Heinemann, T., et al. (2009). Universals and cultural variation in turn-taking in conversation. *Proc. Natl. Acad. Sci. U.S.A.* 106, 10587–10592. doi: 10.1073/pnas.0903616106

Swisher, M. V. (1999). "Learning to converse: how deaf mothers support the development of attention and conversational skills in their young deaf children," in *The Deaf Child in the Family and at School*, eds P. E. Spencer, C. J. Erting, & M. Marschark (London: Psychology Press), 41–60. doi: 10.4324/9781410604699-9

Vandell, D. L., and George, L. B. (1981). Social interaction in hearing and deaf preschoolers: successes and failures in initiations. *Child Dev.* 52, 627–635. doi: 10.2307/1129183

Waxman, R., and Spencer, P. (1997). What mothers do to support infant visual attention: Sensitivities to age and hearing status. *J. Deaf Stud. Deaf Educ.* 2, 104–114.

Wood, D. J., Wood, H. A., Griffiths, A. J., Howarth, S. P., and Howarth, C. I. (1982). The structure of conversations with 6-to 10-year-old deaf children. *J. Child Psychol. Psychiatry* 23, 295–308. doi: 10.1111/j.1469-7610.1982.tb00074.x

Yngve, V. H. (1970). "On getting a word in edgewise," in *Paper Presented at the Chicago Linguistics Society, 6th Meeting*, (Chicago: Chicago Linguistic Society), 567–578.

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# Do parents modify child-directed signing to emphasize iconicity?

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Iconic signs are overrepresented in the vocabularies of young deaf children, but it is unclear why. It is possible that iconic signs are easier for children to learn, but it is also possible that adults use iconic signs in child-directed signing in ways that make them more learnable, either by using them more often than less iconic signs or by lengthening them. We analyzed videos of naturalistic play sessions between parents and deaf children ($n$=24 dyads) aged 9–60 months. To determine whether iconic signs are overrepresented during child-directed signing, we compared the iconicity of actual parent productions to the iconicity of simulated vocabularies designed to estimate chance levels of iconicity. For almost all dyads, parent sign types and tokens were not more iconic than the simulated vocabularies, suggesting that parents do not select more iconic signs during child-directed signing. To determine whether iconic signs are more likely to be lengthened, we ran a linear regression predicting sign duration, and found an interaction between age and iconicity: while parents of younger children produced non-iconic and iconic signs with similar durations, parents of older children produced non-iconic signs with shorter durations than iconic signs. Thus, parents sign more quickly with older children than younger children, and iconic signs appear to resist that reduction in sign length. It is possible that iconic signs are perceptually available longer, and their availability is a candidate hypothesis as to why iconic signs are overrepresented in children's vocabularies.

KEYWORDS

**iconicity, American Sign Language, child-directed language, parent input, sign duration, deafness, language development**

## Introduction

All natural human languages–both signed and spoken–contain a range of iconic and arbitrary lexical items (Dingemanse et al., 2015; Winter et al., 2017). In spoken languages, in addition to onomatopoeia, the sounds of words can sometimes reflect aspects of their meanings (e.g., recruiting aspects of the speech signal such as intensity to reference words relating to loudness or excitement). In sign languages, the forms of signs can resemble many aspects of the referent's size, shape, movement, and texture. Although iconicity is a feature of language across modalities, perhaps due to the affordances of the manual visual modality, it remains more heavily associated with signed languages than with spoken languages (Armstrong and Wilcox, 2007; Meir et al., 2013; Perlman et al., 2018).

## Iconicity and language learning

A growing body of evidence indicates that language learners capitalize on iconicity when learning new lexical items. Adult sign language learners are sensitive to iconic form-meaning mappings (Campbell et al., 1992; Baus et al., 2013), sometimes retaining information about iconicity at the expense of phonology (Ortega and Morgan, 2015). Children, too, are sensitive to iconicity in first language acquisition; parent reports of the vocabularies of deaf signing children show high levels of iconicity, and deaf signing toddlers both comprehend and produce iconic signs more often than non-iconic signs (Thompson et al., 2012, Caselli and Pyers, 2017; Caselli et al., 2017; in BSL: Vinson et al., 2008; in TSL: Sumer et al., 2017). Young children learning spoken languages also show an advantage in learning iconic versus non-iconic words (Imai et al., 2008; Kantartzis et al., 2011; Yoshida, 2012; Imai and Kita, 2014; Perry et al., 2018), and hearing preschoolers learn novel iconic manual symbols more quickly than non-iconic items (Marentette and Nicoladis, 2011; Magid and Pyers, 2017; Ortega et al., 2017). Interestingly, children's ability to capitalize on the effects of iconicity for word learning seems to interact with their age, with older children learning iconic signs better than younger children (Tolar et al., 2008; Thompson et al., 2012; Magid and Pyers, 2017).

## Learner-centered mechanisms

The mechanisms underlying the effects of iconicity in first language acquisition remain unclear. One set of explanations are what we will term 'learner-centered' mechanisms. These appeal to the notion that children are themselves sensitive to iconic mappings and leverage them to learn new words. One example of this kind of theory is Imai and Kita's (2014) sound-symbolism bootstrapping theory, in which children take advantage of an innate ability to map and integrate multi-modal input in order to break into the referential system of language. In essence, sound symbolism bootstraps children's ability to understand the referential relationship between speech sounds and meaning, which serves as the foundation for building their lexical representations. Similarly, another learner-centered theory might draw upon the structure mapping theory of iconicity (Gentner, 1983; Emmorey, 2014), which suggests that the signer draws an analogy between a mental representation of a concept (e.g., a semantic representation of drinking) and the mental representation of its sign form (e.g., a curved handshape moving to the mouth). In this sort of account, children must have the cognitive capacity to recognize the link between form and meaning.

## Input-centered mechanisms

The other set of explanations for children's apparent affinity toward iconic signs is 'input-centered.' Under this account, adults (either consciously or unconsciously) produce iconic signs in child-directed signing in ways that make these signs more learnable. Patterns in how iconic signs are produced in the input might sufficiently explain most effects of iconicity on acquisition. For example, if iconic signs are used more frequently with children, their frequency alone—and not their iconicity *per se*—might account for their overrepresentation in children's early vocabularies. Some have hypothesized that child-directed signing may also include the selection of more iconic signs compared to non-iconic signs (Pizer et al., 2011), and in spoken languages, highly iconic ("sound symbolic") words are more prevalent in child-directed speech than in adult-directed speech (Perry et al., 2015, 2021).

Beyond over-representing iconic signs in their input to children, parents may modify iconic signs during child-directed signing by lengthening, repeating, or enlarging them (Perniss et al., 2018). These differences in how iconic signs are produced are also the characteristics of child-directed signing that are often associated with capturing and maintaining children's attention (Pizer et al., 2011). Here too, the ways iconic signs are produced may account for their overrepresentation in children's early vocabularies. Support for this account comes from a longitudinal case study of two Deaf mothers using Israeli Sign Language with their hearing children, reporting that signs were most likely to be repeated, lengthened, enlarged, or displaced ("phonetically modified") when children are aged 10–14 months, but more likely to be produced with an iconic modification—using iconic mimetic body/mouth/vocal gestures—when children are aged 16–20 months (Fuks, 2020). These results offer early suggestions that parents may systematically produce iconic signs in child-directed interactions in ways that make them easily learned.

## The current study

Learner-centered and input-centered explanations are not mutually exclusive; both forces may be at play in acquisition. Children may leverage their ability to detect iconic mappings to learn new words, and adults may also highlight iconic signs by overrepresenting them in their input and/or modifying them to make them more salient for their children to learn. The current study explores two input-centric ways that child-directed signing might be systematically structured to highlight iconic signs. First, we ask whether parents' produce iconic signs more often than non-iconic signs with their children, indicating that they are over-representing iconic signs in their interactions with their children. Second, we ask whether parents produce iconic signs with longer durations than non-iconic signs, providing children more time to perceive them, which could in turn make them more learnable. Because the role of iconicity on children's vocabulary acquisition is impacted by developmental stage, we were most interested to see if these characteristics of iconicity in child-directed signing vary as a function of age. We test these hypotheses by analyzing the use of iconic signs in child-directed signing in a corpus of naturalistic parent–child play interactions in American Sign Language (ASL). The present study is not designed to empirically test any relationships between child-directed signing and child acquisition; rather, by identifying whether iconic signs are highlighted in child-directed signing, we aim to determine whether these input-centered mechanisms are viable hypotheses that account for the advantage of iconicity in child acquisition.

# Materials and methods

## Participants

Participants included 24 parent–child dyads who participated in a naturalistic play session as part of a larger study on ASL development. The children were all deaf and ranged from 9 to 60 months of age ($M=36$, $SD=15$). There were 8 females and 16 males. The children's reported race was White ($n=18$), Asian ($n=1$), African American ($n=1$), more than one race ($n=2$), or unreported ($n=2$). Three children had a reported ethnicity as Hispanic/Latinx and 21 as not Hispanic/Latinx. Parents were deaf ($n=15$) or hearing ($n=9$), and all parents used ASL to communicate with their deaf child. The interactions were conducted at five sites in the Northeast and Midwest US.

## Data sources

### ASL-PLAY

The ASL Parent input and Language Acquisition in Young children (ASL-PLAY) dataset is a corpus of naturalistic interactions between parents and their deaf children (Lieberman et al., 2021; Lieberman, 2022). Parents and children were recorded while engaged in a free play interaction. Parents were provided with a standard set of toys including a wooden fruit set, a Lego train set, toy vehicles, and a farmhouse set. Parents were instructed to play as they typically would with their child. Play sessions lasted for approximately 15 min and were recorded from three separate angles to obtain clear views of both the child and parent.

Twelve minutes of each video (beginning one minute after the start of the recording) were coded and analyzed off-line. Videos were coded in ELAN [Crasborn and Sloetjes, 2008; ELAN (Version 5.8), 2019] for a range of features. Signs were glossed individually using the ASL SignBank, a standardized glossing system for ASL (Hochgesang et al., 2020). All signs, English translations, and attention-getters in the ASL-PLAY dataset were annotated using this system by deaf ASL-signing researchers. Signs were tagged individually to capture the onset and offset of each sign. The onset of the sign was defined as the first frame where the sign was identifiable within the sign stream, which typically included the initiation of the movement component of the sign. The offset was the last frame where the sign was still identifiable before transitioning to the next sign.

### ASL-LEX

ASL-LEX 2.0 is a publicly available online database containing linguistic information for 2,723 ASL signs, selected based on previously published databases, psycholinguistic experiments, and vocabulary tests (Caselli et al., 2017; ASL-LEX 2.0, 2021; Sehyr et al., 2021). It is unclear whether ASL-LEX is representative of the entire lexicon of ASL, and it excludes large pockets of the lexicon (e.g., classifiers); regardless, it is the most comprehensive and only database available. Each sign entry contains detailed lexical and phonological information. Of relevance to this project are the metrics for iconicity, repeated movement, and sign frequency; they are described in detail below. All of the signs in ASL-LEX are cross-referenced with the signs in SignBank, allowing us to merge the lexical data from ASL-LEX with the data from the corpus.

**Iconicity Ratings**: The iconicity estimates in ASL-LEX were derived by averaging over the ratings from 30 hearing non-signers who evaluated how much each sign resembled its meaning (1 = not iconic at all, 7 = very iconic). ASL-LEX also has iconicity ratings from deaf signers for a subset of signs. We chose to use the iconicity ratings from non-signers because ratings from non-signers highly correlate with the ratings from deaf signers (Sehyr and Emmorey, 2019), and were available for the full set of signs in ASL-LEX. The signs in ASL-LEX skew towards being non-iconic, with 66% of signs having an iconicity rating below 4 on a scale of 1–7 (Caselli et al., 2017).

**Repeated Movement**: Each sign in the database is noted as having repeated movement or not. Movement repetition includes repetition of path movements, hand rotation, or handshape change (Sehyr et al., 2021).

**Sign Frequency**: Because there is not a large enough corpus of ASL to robustly estimate lexical frequency, we used the subjective estimates of frequency from ASL-LEX. The frequency estimates in ASL-LEX were averaged over ratings from 25–35 deaf adults who rated how often each sign appears in everyday conversation (1 = very infrequently, 7 = very frequently; Sehyr et al., 2021).

## Data preparation

We extracted all parent sign tokens from participants in the ASL-PLAY dataset (pairs of SignBank Annotation IDs and a timestamp of the duration of the sign in milliseconds), generating a dataset that included 6,294 adult sign tokens from the 24 participants (Per family; $Min=68$, $Max=506$, $Mean=262$).

We identified and removed all point tokens ($n=1,256$). Points (also called indexes) carry linguistic meaning in ASL; they can serve as pronouns and can also be used to draw attention to an object or event. They were used much more frequently than any other sign; for comparison, the next most common sign type was used 199 times across all parents. Because of their unique linguistic function and the difficulty of assessing their iconicity, we excluded them from the analysis.

We then removed an additional 138 types ($n=1,256$ tokens) from the dataset consisting of depicting signs, fingerspelled words, gestures, pronouns, idioms, and name signs. These signs did not have an iconicity rating (or a corresponding entry) in ASL-LEX.

Most of the signs in ASL-LEX and SignBank have a 1:1 correspondence, and so can be straightforwardly matched to the ASL-PLAY dataset. Nevertheless, there were some instances in which a sign in the corpus corresponded to two entries in ASL-LEX due to different phonological or inflectional variants (e.g., EAT) with slightly different iconicity ratings; for these cases ($n=29$ types), we randomly selected one of the two possible matches from ASL-LEX.[1]

The final corpus had 3,782 adult sign tokens representing 371 sign types from 24 participants.

# Results

## Describing parent productions

In order to determine the extent to which each parent favored iconic signs in their signing, we computed a unique mean iconicity rating for each of the 24 parents based on that parent's sign tokens and types. The total number of tokens per parent ranged from 48 to 318 ($M=157$, $SD=65$). Average parent token iconicity ranged from 2.7 to 4.0 ($M=3.2$, $SD=0.3$). Parent token iconicity did not differ significantly by parent hearing status ($t\ (22)=-0.8\ p>0.1$). Additionally, there was no relationship between the average iconicity of parent sign tokens and their child's age (rho = 0.03, $p=>0.1$). Number of parent sign types ranged from 23–103 ($M=57$, $SD=21$), and the average iconicity of those sign types ranged from 2.7–3.6 ($M=3.2$, $SD=0.2$). Across all family tokens, the distribution of parent sign tokens by lexical category (taken from ASL-LEX), was as follows: 1125 nouns (30%), 1,090 verbs (29%), 778 minor class items (21%), 455 adjectives (12%), 282 adverbs (7%), and 52 numbers (1%). A table summarizing the participant data from all 24 families is included in the Appendix.

## Iconicity of child-directed signs relative to ASL-LEX

We first asked whether parents' child-directed signs were more iconic than one might expect by chance. To do this, we compared bootstrapped estimates of the iconicity of the sign types the parents actually used with their children during the session (Parent Vocabularies) to simulated vocabularies of the same number of items randomly drawn from the ASL-LEX database (Simulated Vocabularies) to represent the "lexicon" of each parent during the play session. We also conducted a parallel analysis of sign tokens by comparing all individual tokens the parents produced with their children to simulated vocabularies with the same number of items randomly drawn from ASL-LEX, but with replacement so the same item could appear more than once to account for individual token productions. To control for lexical frequency in the simulated vocabularies, for both tokens and types, the random samples from ASL-LEX were weighted by frequency. The simulated vocabularies were designed to estimate how iconic a set of signs might be by chance. We bootstrapped Parent Vocabularies by randomly sampling from a subset of either tokens or types from each parent's attested items, calculated the mean iconicity rating of each subsample, and repeated this process 1,000 times. We then paired one Simulated Vocabulary with one Parent Vocabulary and calculated the difference in mean iconicity of each vocabulary. We visualized the distribution of the 1,000 difference scores for each of the 24 parents in Figure 1.

If parents' vocabularies were significantly more iconic than chance, we would expect the difference between the bootstrapped Parent Vocabularies and the Simulated Vocabularies to be significantly larger than zero (i.e., 0 should fall below the 95% CI). Instead, what we found is that for both tokens and types, the mean iconicity of the bootstrapped Parent Vocabularies is comparable to the Simulated Vocabularies. For sign types, the iconicity estimates of all the Parent Vocabularies were indistinguishable from zero. The same is largely true of the tokens, though two parents used iconic signs more often than chance (probability <0.025), suggesting that those two parents may systematically repeat iconic signs (Figure 1). Contrary to our predictions, iconic signs were not overrepresented in child-directed signing.

## What factors predict sign duration in parent input?

We next sought to determine whether more-iconic signs were produced with longer duration relative to less-iconic signs. We ran a linear mixed-effect model to determine whether iconicity of parent sign productions predicted their duration. The dependent variable was token duration. The critical predictor was an interaction between iconicity and age. Two other control variables that may influence duration were drawn from ASL-LEX: (1) repeated movement, since signs that had repetition would take physically longer to produce, and (2) sign frequency. We included sign frequency because it is often inversely related to phonetic duration, as seen across spoken languages (e.g., Gahl et al., 2012), and in Swedish Sign Language (Börstell et al., 2016). Finally, the model included parent hearing status and random effects for participants (Table 1).

1 To ensure that this approach did not unduly influence the analysis, we repeated a parallel set of analysis in which we selected the highest of the two iconicity ratings for each item rather than a random selection. The results were qualitatively the same.

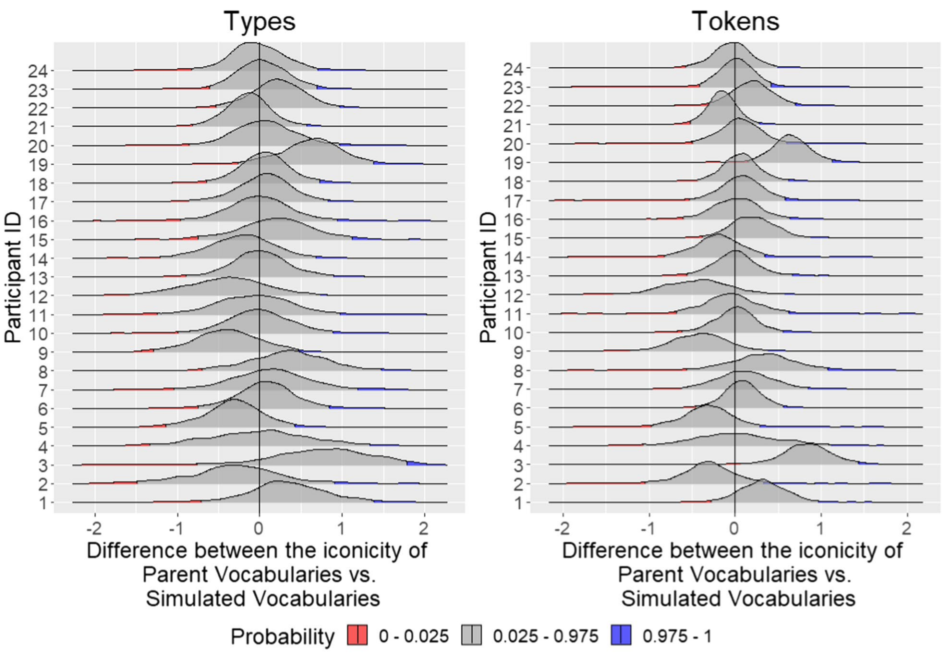


FIGURE 1
The distribution of difference in mean iconicity of 1,000 pairs of Parent Vocabularies and Simulated Vocabularies. The upper and lower bounds of the 95% confidence interval are illustrated in blue and red, respectively. Distributions that largely fall above zero (i.e., the lower bound of the 95% CI is above 0) indicate that parents' signs were more iconic than chance. In the left panel, iconicity ratings were averaged over sign types, and in the right panel over sign tokens. With the exception of two parents' tokens (participants 3 and 19), Parent Vocabularies were no more iconic than would be expected by chance.

TABLE 1 Results of the model predicting sign duration.

| Predictors | Adult sign duration | | |
|---|---|---|---|
| | Estimates | CI | p |
| (Intercept) | 1.05 | 0.85–1.25 | <0.001 |
| Iconicity | −0.03 | −0.05–0.00 | 0.088 |
| Repeated movement | 0.10 | 0.06–0.13 | <0.001 |
| Frequency in lexicon | −0.08 | −0.10– −0.06 | <0.001 |
| Child age | −0.00 | −0.01– −0.00 | 0.064 |
| Parent hearing status | −0.03 | −0.17–0.10 | 0.626 |
| Iconicity x Age | 0.00 | 0.00–0.00 | 0.038 |

There were significant positive effects of repeated movement, and significant negative effects of sign frequency, child age, and the interaction between iconicity and age.

In support of the hypothesis, there was an interaction between iconicity and age. Visualization of the model (Figure 2) illustrates that parents of younger children had similar sign durations for iconic and non-iconic signs, but parents of older children had shorter durations for non-iconic signs. Simple slopes analyses confirmed this pattern; the only slope that was marginally different from zero was that of the oldest children ($B = 0.02(3612.4)$, $SE = 0.008$, $p = 0.053$). Notably, for the older children, the parents' iconic signs had similar durations to those of the parents' of the younger children. This finding provides weak evidence that parents may begin to shorten non-iconic signs as their children get older, but that iconic signs seem to resist shortening.

## Discussion

We examined a corpus of parent interactions with deaf children to investigate iconicity in child-directed signing. First, we found that the average iconicity of parent productions were largely no different than chance (i.e., than the average iconicity of a random sample of signs drawn from the larger ASL lexicon). Only two of the 24 parents produced sign tokens that were more iconic than expected by chance. This pattern suggests that the frequency of iconic signs in child-directed signing is an unlikely explanation for the previously documented advantage for iconic signs in children's vocabularies. Second, we found patterns in our data suggesting that sign duration in child-directed signing may be systematically different for highly iconic and less iconic signs as a function of age: while parents of younger children had similar sign durations for both low and high iconicity signs, parents of older children had shorter duration for low iconicity signs than high iconicity signs. If this pattern holds in future studies, we would take it to indicate that the duration of the iconic signs stays constant as children grow. That is, while parents shorten the articulation of low iconicity signs, iconic signs resist this reduction, leading to increased salience of iconic signs in the input and a corresponding advantage in the acquisition of these signs.

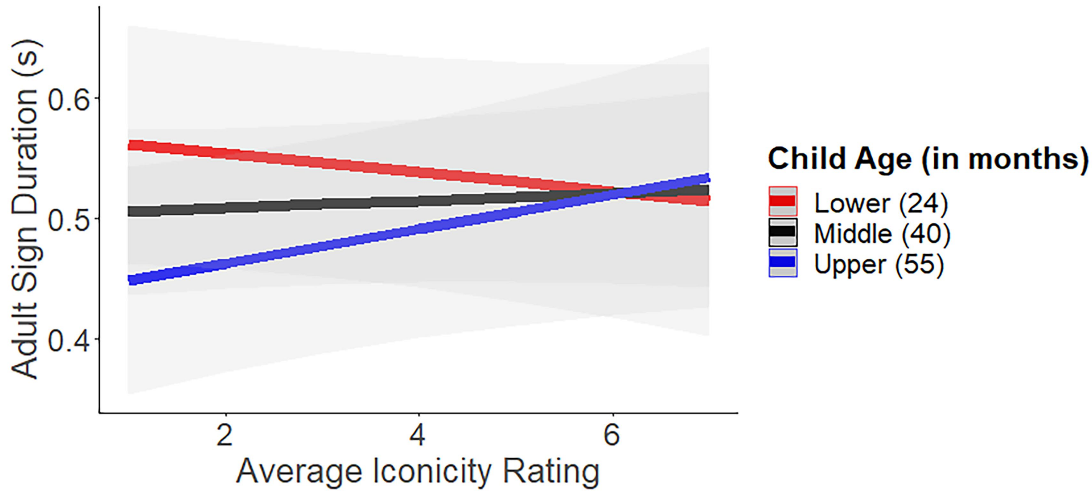


FIGURE 2
The interaction between sign duration, iconicity and child age in months. For younger and middle-aged children sign duration was similar regardless of the sign's iconicity rating, but for older children sign duration was shorter for non-iconic signs than iconic signs. The lines indicate the children's mean age and +/− one standard deviation.

## Prevalence of iconic lexical items in parent input

The fact that parents did not overrepresent iconic signs when signing with their children is somewhat different from previous work on use of iconic words in child-directed speech; Perry et al. (2018) found that parent–child conversations use highly iconic words more frequently than adult conversations. This difference may be methodological: the children in our sample had a wider age range and were, on average, older than those in Perry et al. (2018), and the toys available for dyads to play with during the present play sessions may not have elicited especially iconic signs. Alternatively, it could be that there are modality differences in child-directed language in signed vs. spoken languages. Sign languages are more iconic overall than spoken English (Dingemanse et al., 2015; Perlman et al., 2018), and so inflating the rates of iconicity may not be natural to parents; since the language already makes use of iconic form-meaning mappings, inflating those iconic mappings further might not be intuitive.

## Differential modification of iconic signs

We found that the duration of iconic signs varies systematically in children's input, whereby parents produce iconic signs for longer than less iconic signs, but this effect depends on age. With the youngest children in our sample, parents did not vary their sign duration as a function of degree of iconicity. For the older children in our sample (age four years and up) parents produced iconic signs for longer than less iconic signs. This finding aligns with prior literature on modifications of child-directed signing (Perniss et al., 2018), and with studies showing that the effect of iconicity on children's acquisition is greatest among older hearing children (aged 3+; Namy et al., 2004; Tolar et al., 2008) rather than younger ones (aged 18–24 months; Perry et al., 2021).

However, much of the research concerning iconicity in early sign language acquisition targets children within the first 20 months (10–14 months- Massaro and Perlman, 2017; 21–30 months- Thompson et al., 2012). While the older children in the current study may see iconic signs for longer, they may have already acquired those signs. So, the function of parents' lengthening of iconic signs in their child directed signing to older children remains unclear.

There are two ways to consider the observed interaction between iconicity and age on sign duration: parents may lengthen iconic signs or reduce non-iconic signs. Because the length of iconic signs is similar for parents of younger and older children, our interpretation is that iconic signs resist reduction. Lengthening is a common property of child-directed signing (e.g., Holzrichter and Meier, 2000; Pizer et al., 2011), and as children grow parents typically produce signs more rapidly. This study suggests that iconic signs resist this shortening of sign duration and remain similar in length to the input much younger children receive.

While the present study is not designed to determine whether increased sign duration causes children to more readily learn signs, it suggests that an 'input centric' mechanism is a viable explanation as to why iconic signs are overrepresented in older children's early vocabularies: iconic signs are perceptually available for longer, which may make them easier for children to learn. Another mutually compatible possibility is that parents lengthen iconic signs *in response* to children's acquisition, lengthening these signs because they are aware that children are learning them. More work is needed to identify the nature of the relationship between the lengthening of iconic signs in child-directed signing and acquisition of those signs.

## The role of visual attention

We speculate that children's ability to monitor and manage their own visual attention may partially explain the influence of child age on parent sign duration. Specifically, older children are better able to control their visual attention, so they are more likely to be looking at their parents when signs are produced. Pizer et al. (2011) found a significant association between child eye gaze and parent sign duration, with parents producing longer signs when they did not have eye contact with their child. It is likely that children in the current study were old enough to skillfully manage their own attention, resulting in parents producing shorter signs overall but maintaining the increased length of iconic signs due to their phonological form or other factors. Future studies that take into account children's eye gaze to the parent during interaction will help shed light on this possibility.

## Limitations and future directions

Our analysis looked only at lexicalized signs which had a corresponding entry in ASL-LEX that included an iconicity rating. Depicting signs show appearance, location, and/or movement- are often transparently iconic, but were excluded from analysis here. In addition to the iconicity of the manual components of depicting signs, signers often produce accompanying mouth movements that are temporally aligned with the production of the sign and depict the referent's size and shape in iconic ways (Lu and Goldin-Meadow, 2018). Importantly, if lexical signs do not map neatly onto their referents, depicting signs may be used instead to better align with an iconic mapping (Lu and Goldin-Meadow, 2018), which may increase the overall iconic properties of child-directed signing, even within our corpus. How iconicity influences parents' production of depicting signs may very well be different from the lexical items in this study, and merits further exploration.

In the current study we investigated the hypothesis that the sign duration of iconic signs may be longer than non-iconic signs. In addition to lengthening, parents may specifically highlight iconic signs by repeating them, displacing them into the child's view, using an unconventional place of articulation, or even attempting to explain the iconic properties of the sign (e.g., Pizer et al., 2011). Perniss et al. (2018) found that parents modify iconic signs more than non-iconic signs, particularly in non-ostensive naming contexts. While these findings support our work, it is important to note that all our contexts were ostensive, with the toys present throughout the interaction, which may have impacted the likelihood of iconic signs being lengthened. Though Perniss et al. do not report the proportion of each kind of modification in their study (enlargement, repetition, and lengthening), Fuks (2020) found that when signs were phonetically modified, they were most likely to be repeated or enlarged, not lengthened. Seeing as our study did not analyze other forms of modification, iconic signs may have been emphasized in other ways within the corpus. Moreover, the kind of modification that parents apply to iconic signs may specifically illustrate the iconicity of the sign. For example, signs referencing large objects might be more likely to be enlarged, signs referencing slow objects might be more likely to be lengthened, etc. Signs can be iconic of their referent in a myriad of ways, and parents can highlight that iconicity by using many forms of modification. More research is needed to examine these other ways that iconic signs may be modified in child-directed signing, especially in naturalistic contexts.

# Conclusion

This study of parent input during naturalistic ASL interactions revealed that parents do not preferentially use iconic signs, but may lengthen their sign productions as a function of iconicity for older children. Increased sign duration may support children's acquisition of iconic signs, but more work is needed to determine whether there is a causal relationship between the length of iconic signs in input and their acquisition. Though we find effects of iconicity in child-directed signing, the effects were subtle. Thus, we await a more nuanced analysis of other types of sign modifications to better understand how input-centered mechanisms might relate to the acquisition of iconic signs. The current study contributes to our understanding of how iconic signs are produced in child-directed signing, and lays groundwork for investigations of the relationship between child-directed signing and child vocabulary acquisition.

# Data availability statement

The data that support the findings of this study are available upon reasonable request from the corresponding author.

# Ethics statement

The studies involving human participants were reviewed and approved by the Boston University IRB. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

# Author contributions

PG conceptualized the study, prepared the data, and conducted the analyses. AL helped to collect the data for the ASL-PLAY dataset and contributed to data analysis. NC collected the data for the ASL-LEX database and contributed to data analysis. JP contributed to data analysis. All authors contributed to writing the manuscript and approved the submitted version.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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## References


Armstrong, D. F., and Wilcox, S. E. (2007). *The Gestural Origin of Language*. New York: Oxford University Press.

ASL-LEX 2.0 (2021). Visualizing the ASL Lexicon. Available at: asl-lex.org

Baus, C., Carreiras, M., and Emmorey, K. (2013). When does iconicity in sign language matter? *Lang. Cognit. Process.* 28, 261–271. doi: 10.1080/01690965.2011.620374

Börstell, C., Hörberg, T., and Östling, R. (2016). Distribution and duration of signs and parts of speech in Swedish sign language. *Sign Lang. Linguist.* 19, 143–196. doi: 10.1075/sll.19.2.01bor

Campbell, R., Martin, P., and White, T. (1992). Forced choice recognition of sign in novice learners of British sign language. *Appl. Linguist.* 13, 185–201. doi: 10.1093/applin/13.2.185

Caselli, N. K., and Pyers, J. E. (2017). The road to language learning is not entirely iconic: iconicity, neighborhood density, and frequency facilitate Acquisition of Sign Language. *Psychol. Sci.* 28, 979–987. doi: 10.1177/0956797617700498

Caselli, N. K., Sehyr, Z. S., Cohen-Goldberg, A. M., and Emmorey, K. (2017). ASL-LEX: A lexical database of American sign language. *Behav. Res.* 49, 784–801. doi: 10.3758/s13428-016-0742-0

Crasborn, O., and Sloetjes, H. (2008). Enhanced ELAN functionality for sign language corpora. In: Proceedings of LREC 2008, Sixth International Conference on Language Resources and Evaluation, 39–43. Available at: https://pure.mpg.de/pubman/faces/ViewItemOverviewPage.jsp?itemId=item_61042 (Accessed June 1, 2020).

Dingemanse, M., Blasi, D. E., Lupyan, G., Christiansen, M. H., and Monaghan, P. (2015). Arbitrariness, iconicity, and systematicity in language. *Trends Cogn. Sci.* 19, 603–615. doi: 10.1016/j.tics.2015.07.013

ELAN (Version 5.8) (2019). Nijmegen: Max Planck Institute for Psycholinguistics, The Language Archive. Available at: https://archive.mpi.nl/tla/elan (Accessed July 25, 2022).

Emmorey, K. (2014). Iconicity as structure mapping. *Philos. Trans. Royal Soc. B: Biol. Sci.* 369:20130301. doi: 10.1098/rstb.2013.0301

Fuks, O. (2020). Developmental path in input modifications and the use of iconicity in early hearing infant–deaf mother interactions. *Am. Ann. Deaf* 165, 418–435. doi: 10.1353/aad.2020.0028

Gahl, S., Yao, Y., and Johnson, K. (2012). Why reduce? Phonological neighborhood density and phonetic reduction in spontaneous speech. *J. Mem. Lang.* 66, 789–806. doi: 10.1016/j.jml.2011.11.006

Gentner, D. (1983). Structure-Mapping: A Theoretical Framework for Analogy* - Gentner - 1983 - Cognitive Science-Wiley Online Library. Available at: https://onlinelibrary-wiley-com.ezproxy.bu.edu/doi/abs/10.1207/s15516709cog0702_3 (Accessed April 14, 2022).

Hochgesang, J., Crasborn, O., and Lillo-Martin, D. (2020). ASL Signbank. Available at: https://aslsignbank.haskins.yale.edu/about/conditions/ (Accessed June 16, 2020).

Holzrichter, A. Z., and Meier, R. P. (2000). "Child-directed signing in American sign language," in *Language Acquisition By Eye*. eds. C. Chamberlain, J. P. Morford and R. I. Mayberry (Mahwah, NJ: Lawrence Erlbaum Associates), 25–40.

Imai, M., and Kita, S. (2014). The sound symbolism bootstrapping hypothesis for language acquisition and language evolution. *Philos. Trans. R. Soc. Lond. Ser. B Biol. Sci.* 369:20130298. doi: 10.1098/rstb.2013.0298

Imai, M., Kita, S., Nagumo, M., and Okada, H. (2008). Sound symbolism facilitates early verb learning. *Cognition* 109, 54–65. doi: 10.1016/j.cognition.2008.07.015

Kantartzis, K., Imai, M., and Kita, S. (2011). Japanese sound-symbolism facilitates word learning in English-speaking children. *Cogn. Sci.* 35, 575–586. doi: 10.1111/j.1551-6709.2010.01169.x

Lieberman, A. (2022). The American Sign Language Parent Input and Language Acquisition in Young Children (ASL-PLAY) dataset. Available at: osf.io/3w8ka

Lieberman, A. M., Fitch, A., and Gagne, D. (2021). The Social Dynamics of Joint Attention in American Sign Language Interactions. Talk presented at the International Association for the Study of Child Language [virtual].

Lu, J. C., and Goldin-Meadow, S. (2018). Creating images with the stroke of a hand: depiction of size and shape in sign language. *Front. Psychol.* 9. Available at: https://www.frontiersin.org/article/10.3389/fpsyg.2018.01276 (Accessed June 20, 2022).

Magid, R. W., and Pyers, J. E. (2017). "I use it when I see it": The role of development and experience in deaf and hearing children's understanding of iconic gesture. *Cognition* 162, 73–86. doi: 10.1016/j.cognition.2017.01.015

Marentette, P., and Nicoladis, E. (2011). Preschoolers' interpretations of gesture: Label or action associate? *Cognition* 121, 386–399. doi: 10.1016/j.cognition.2011.08.012

Massaro, D. W., and Perlman, M. (2017). Quantifying Iconicity's contribution during language acquisition: implications for vocabulary learning. Frontiers in Communication 2. Available at: https://www.frontiersin.org/article/10.3389/fcomm.2017.00004 (Accessed June 20, 2022).

Meir, I., Padden, C., Aronoff, M., and Sandler, W. (2013). Competing iconicities in the structure of languages. *Cogn. Linguist.* 24, 309–343. doi: 10.1515/cog-2013-0010

Namy, L. L., Campbell, A. L., and Tomasello, M. (2004). The changing role of iconicity in non-verbal symbol learning: A U-shaped trajectory in the acquisition of arbitrary gestures. *J. Cogn. Dev.* 5, 37–57. doi: 10.1207/s15327647jcd0501_3

Ortega, G., and Morgan, G. (2015). The effect of iconicity in the mental lexicon of hearing non-signers and proficient signers: Evidence of cross-modal priming. *Lang. Cogn. Neurosci.* 30, 574–585. doi: 10.1080/23273798.2014.959533

Ortega, G., Sümer, B., and Özyürek, A. (2017). Type of iconicity matters in the vocabulary development of signing children. *Dev. Psychol.* 53, 89–99. doi: 10.1037/dev0000161

Perlman, M., Little, H., Thompson, B., and Thompson, R. L. (2018). Iconicity in signed and spoken vocabulary: A comparison between American sign language, British sign language, English, and Spanish. *Front. Psychol.* 9. Available at: https://www.frontiersin.org/article/10.3389/fpsyg.2018.01433 (Accessed April 14, 2022).

Perniss, P., Lu, J. C., Morgan, G., and Vigliocco, G. (2018). Mapping language to the world: the role of iconicity in the sign language input. *Dev. Sci.* 21:e12551. doi: 10.1111/desc.12551

Perry, L. K., Custode, S. A., Fasano, R. M., Gonzalez, B. M., and Savy, J. D. (2021). What is the buzz about iconicity? How iconicity in caregiver speech supports Children's word learning. *Cogn. Sci.* 45:e12976. doi: 10.1111/cogs.12976

Perry, L. K., Perlman, M., and Lupyan, G. (2015). Iconicity in English and Spanish and its relation to lexical category and age of acquisition. *PLoS One* 10:e0137147. doi: 10.1371/journal.pone.0137147

Perry, L. K., Perlman, M., Winter, B., Massaro, D. W., and Lupyan, G. (2018). Iconicity in the speech of children and adults. *Dev. Sci.* 21:e12572. doi: 10.1111/desc.12572

Pizer, G., Meier, R. P., and Points, K. S. (2011). Child-directed signing as a linguistic register. In: Formational Units in Sign Languages, eds. R. Channon and H. van der Hulst (Nijmegen/Berlin: Ishara Press/Mouton de Gruyter), 65–84. Available at: https://www.degruyter.com/view/book/9781614510680/10.1515/9781614510680.65.xml (Accessed June 2, 2020).

Sehyr, Z. S., Caselli, N., Cohen-Goldberg, A. M., and Emmorey, K. (2021). The ASL-LEX 2.0 project: A database of lexical and phonological properties for 2,723 signs in American sign language. *J. Deaf Stud. Deaf Educ.* 26, 263–277. doi: 10.1093/deafed/enaa038

Sehyr, Z. S., and Emmorey, K. (2019). The perceived mapping between form and meaning in American sign language depends on linguistic knowledge and task: evidence from iconicity and transparency judgments. *Lang. Cogn.* 11, 208–234. doi: 10.1017/langcog.2019.18

Sumer, B., Grabitz, C., and Küntay, A. (2017). Early produced signs are iconic: evidence from Turkish sign language. In (cognitive science society), 3273–3278. Available at: https://pure.mpg.de/pubman/faces/ViewItemOverviewPage.jsp?itemId=item_2451636 (Accessed June 20, 2022).

Thompson, R. L., Vinson, D. P., Woll, B., and Vigliocco, G. (2012). The road to language learning is iconic: evidence from British sign language. *Psychol. Sci.* 23, 1443–1448. doi: 10.1177/0956797612459763

Tolar, T. D., Lederberg, A. R., Gokhale, S., and Tomasello, M. (2008). The development of the ability to recognize the meaning of iconic signs. *J. Deaf Stud. Deaf Educ.* 13, 225–240. doi: 10.1093/deafed/enm045

Vinson, D. P., Cormier, K., Denmark, T., Schembri, A., and Vigliocco, G. (2008). The British sign language (BSL) norms for age of acquisition, familiarity, and iconicity. *Behav. Res. Methods* 40, 1079–1087. doi: 10.3758/BRM.40.4.1079

Winter, B., Perlman, M., Perry, L. K., and Lupyan, G. (2017). Which words are most iconic? Iconicity in English sensory words. *Interact. Stud.: Soc. Behav. Commun. Biol. Artif. Syst.* 18, 443–464. doi: 10.1075/is.18.3.07win

Yoshida, H. (2012). A cross-linguistic study of sound symbolism in Children's verb learning. *J. Cogn. Dev.* 13, 232–265. doi: 10.1080/15248372.2011.573515

 10.3389/fpsyg.2022.920729

# Appendix

TABLE A1 Summary of dataset.

| ID # | Child age in months | Parent hearing status | # of raw tokens produced | # of tokens included in analysis | # of sign types | Average iconicity | Average sign duration | Number of nouns | Number of verbs |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 9 | Hearing | 244 | 149 | 43 | 3.44 | 0.58 | 35 | 45 |
| 2 | 12 | Hearing | 181 | 118 | 32 | 2.82 | 0.5 | 55 | 28 |
| 3 | 16 | Hearing | 275 | 164 | 33 | 3.96 | 0.49 | 45 | 56 |
| 4 | 20 | Hearing | 68 | 48 | 23 | 3.15 | 0.63 | 19 | 19 |
| 5 | 25 | Deaf | 215 | 129 | 60 | 2.82 | 0.6 | 40 | 29 |
| 6 | 25 | Deaf | 332 | 210 | 68 | 3.21 | 0.31 | 56 | 43 |
| 7 | 28 | Deaf | 153 | 103 | 47 | 3.25 | 0.49 | 35 | 39 |
| 8 | 29 | Deaf | 128 | 70 | 34 | 3.48 | 0.34 | 12 | 24 |
| 9 | 29 | Hearing | 113 | 82 | 39 | 2.72 | 0.48 | 20 | 12 |
| 10 | 32 | Hearing | 284 | 188 | 60 | 3.12 | 0.53 | 81 | 51 |
| 11 | 33 | Hearing | 152 | 109 | 42 | 3.07 | 0.6 | 25 | 37 |
| 12 | 33 | Deaf | 89 | 54 | 28 | 2.69 | 0.88 | 17 | 18 |
| 13 | 34 | Deaf | 260 | 146 | 63 | 3.12 | 0.38 | 54 | 36 |
| 14 | 35 | Hearing | 235 | 158 | 63 | 2.93 | 0.6 | 69 | 23 |
| 15 | 35 | Deaf | 269 | 131 | 44 | 3.33 | 0.45 | 33 | 26 |
| 16 | 41 | Deaf | 216 | 131 | 60 | 3.13 | 0.6 | 35 | 39 |
| 17 | 38 | Deaf | 290 | 182 | 69 | 3.19 | 0.35 | 36 | 58 |
| 18 | 42 | Deaf | 397 | 222 | 80 | 3.21 | 0.45 | 59 | 33 |
| 19 | 47 | Deaf | 400 | 244 | 67 | 3.76 | 0.51 | 62 | 85 |
| 20 | 56 | Deaf | 360 | 206 | 79 | 3.18 | 0.61 | 69 | 44 |
| 21 | 59 | Deaf | 426 | 318 | 103 | 2.98 | 0.25 | 83 | 85 |
| 22 | 59 | Deaf | 340 | 197 | 84 | 3.33 | 0.22 | 67 | 54 |
| 23 | 59 | Deaf | 506 | 238 | 85 | 3.14 | 0.29 | 40 | 65 |
| 24 | 60 | Hearing | 361 | 185 | 80 | 3.09 | 0.6 | 48 | 55 |

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# Phonological development in American Sign Language-signing children: Insights from pseudosign repetition tasks

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In this study, we conducted a pseudosign (nonce sign) repetition task with 22 children (mean age: 6;04) acquiring American Sign Language (ASL) as a first language (L1) from deaf parents. Thirty-nine pseudosigns with varying complexity were developed and organized into eight categories depending on number of hands, number of simultaneous movement types, and number of movement sequences. Pseudosigns also varied in handshape complexity. The children's performance on the ASL pseudosign task improved with age, displaying relatively accurate (re)production of location and orientation, but much less accurate handshape and movement, a finding in line with real sign productions for both L1 and L2 signers. Handshapes with higher complexity were correlated with lower accuracy in the handshape parameter. We found main effects of sequential and simultaneous movement combinations on overall performance. Items with no movement sequence were produced with higher overall accuracy than those with a movement sequence. Items with two simultaneous movement types or a single movement type were produced with higher overall accuracy than those with three simultaneous movement types. Finally, number of hands did not affect the overall accuracy. Remarkably, movement sequences impose processing constraints on signing children whereas complex hands (two hands) and two simultaneous movement types do not significantly lower accuracy, indicating a capacity for processing multiple simultaneous components in signs. Spoken languages, in contrast, manifest greater complexity in temporal length. Hearing children's pseudoword repetition still displays high levels of accuracy on disyllabic words, with complexity effects affecting only longer multisyllabic words. We conclude that the pseudosign repetition task is an informative tool for studies of signing children's phonological development and that sheds light on potential modality effects for phonological development.

KEYWORDS

**American Sign Language (ASL), pseudosign, child language acquisition, modality, working memory, phonological complexity, non-word repetition task, phonological development**

## Introduction

Early investigations of the sub-lexical structure, or phonology, of sign languages, characterized the form of a sign in terms of four primary 'parameters': handshape, location, movement, and orientation. More recent sign phonological theories have recognized that while the concept of sign parameters is useful, more detailed analyses at the feature level can lead to greater understanding of the ways that sign phonology is organized. These developments have also contributed to a greater understanding of *complexity* in sign language phonology.

For sign languages, lexical and morphological complexities often take the form of simultaneously combined elements, rather than the sequential combinations more typical in spoken languages. This might be related to the fact that sequential memory coding is enhanced in the processing of spoken languages, while spatial memory is superior in the processing of sign languages (for a review, see Giezen, 2021). Sign languages take advantage of this difference by building complexity in primarily monosyllabic units, in which multiple components of information are simultaneously expressed, rather than employing sequences of syllables.

In this study, we ask whether this difference in phonological complexity of sign languages versus spoken languages impacts sign language development. Our data come from analysis of pseudosigns (nonce or non-word signs) reproduced by 4- to 8-year-old native signers of American Sign Language (ASL). The pseudosigns are categorized into those with greater sequential complexity, e.g., containing a sequential movement, and those with greater simultaneous complexity, e.g., involving two hands, layered movement types, or more complex handshapes. We find that, indeed, pseudosigns with a sequential movement are reproduced less accurately than those without sequential movement. On the other hand, signs with two simultaneous movement types are not produced less accurately; only when the complexity level reaches three simultaneous movement types does accuracy decrease. We also find that two-handed pseudosigns are not reproduced less accurately than one-handed pseudosigns, and in this study handshape complexity only relates to the accuracy of handshape reproduction, not overall accuracy of the sign.

In the rest of this introduction section, we provide readers with relevant background information about sign language phonology and sign phonological complexity, previous studies of sign language phonological development, and previous studies using the non-word repetition technique with both spoken and signed languages.

## Sign language phonology

Early linguistic analyses of sign languages (Stokoe, 1960; Battison, 1978) described signs in terms of four main formational components: the configuration of the hand(s) (or handshape), the location on the body or in space in which the sign is made, the movement of the arm/hand/fingers, and the orientation of the hands (e.g., palms facing the signer, or the signer's ipsilateral or contralateral side). Specification of the values for each of these manual 'parameters'[1] allows for the characterization of individual signs, capturing the possibility of minimal pairs that differ in the value of a single such parameter. For example, the signs KNOWbb[2] and THINK (**Figures 1A,C**) share the same location, movement, and orientation, but differ in handshape ( vs. ), while DISAPPOINT and THINK (**Figures 1B,C**) share the same handshape, movement, and orientation, but differ in location (chin vs. forehead).

Today there are many theoretical models of sign language phonology, but they all start with the basic observation that

1 Throughout this manuscript we only attend to manual parameters and generally do not discuss non-manual markings. The term 'parameter' should be understood as referring only to manual components here.

2 In sign language research, individual signs are typically named by using a gloss in upper-case which is a close translation equivalent for at least one sense of the sign. We adopt the identification glosses used in the ASL Signbank (aslsignbank.haskins.yale.edu; Hochgesang et al., 2021), which sometimes employ additional symbols (such as the bb on KNOWbb) to demarcate the specific sign intended. Readers can view videos of the signs glossed in this paper at that website through the links provided in the **Supplementary material**.

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FIGURE 1
Minimal pairs in American Sign Language (ASL) (figures reproduced with permission from ASL Signbank; Hochgesang et al., 2021). **(A)** KNOWbb; **(B)** DISAPPOINT; and **(C)** THINK.

values for these four parameters need to be specified to identify a sign. However, it is also clear that while signs can be decomposed into parameters, the parameters themselves are complex and can be viewed in terms of phonological features (see Section "Scoring" for descriptions of the features that we adopted for the current study). For example, the handshape of KNOWbb (**Figure 1A**) can be described in terms of its selected fingers (all fingers selected), joint position (selected fingers extended), and thumb position (extended). Several models have been proposed to account for the possible patterns observed for hand configurations (Sandler, 1989; Corina and Sandler, 1993; van der Hulst, 1993; van der Kooij, 2002; Sandler and Lillo-Martin, 2006), and some models have also adopted more complex representations for other parameters (movement, location, and orientation) (Brentari, 1998, 2019).

While modern approaches to sign language phonology have progressed well beyond simple parameter-based sign descriptions, the notion of parameters continues to play a large role in psycholinguistics and language acquisition. For that reason, the current project uses both parameter-based and feature-based approaches to compare different types of potential phonological complexity for signs, as well as phonological complexity between signed and spoken languages.

## Phonological complexity in sign languages

Phonological complexity of individual signs can be defined in various ways (Mann et al., 2010; Ortega and Morgan, 2015; Brentari, 2019; Morgan et al., 2019; van der Hulst and van der Kooij, 2021). For example, some signs use one hand (e.g., the three signs illustrated in **Figure 1**), while others use both hands (e.g., ALL-DAY and ANNOTATE). The use of two hands is potentially more complex than the use of one hand only, as it requires additional information to be specified in the sign's lexical entry.

Another way to assess phonological complexity is by considering the complexity of individual parameters such as the handshapes. Each sign language has its inventory of occurring handshapes, which vary across sign languages (Stokoe, 1960; Friedman, 1975; Fenlon et al., 2015; Brentari et al., 2021). A small set of hand configurations has been identified as 'unmarked,' potentially occurring universally across sign languages (Klima and Bellugi, 1979; Boyes Braem, 1990; Marentette, 1995; Marentette and Mayberry, 2000; Sandler and Lillo-Martin, 2006; Henner et al., 2013; Caselli and Pyers, 2017). This identification is based partly on the role of these handshapes in two-handed signs (Battison, 1978).

There are several subcategories of two-handed signs. In *symmetrical* two-handed signs (e.g., ACCEPT and MOCK), both hands assume the same handshape, and there is no special restriction on the handshapes that can be used—they may be more or less complex. However, both hands must have the same location and movement (either simultaneous or in alternation) and the orientation must be symmetrical or identical. In contrast, *asymmetrical* signs (e.g., BUTTER and CONVINCEb) display restrictions on the handshape of the non-dominant hand (also known as the "weak" hand or H2). In an asymmetrical two-handed sign, the non-dominant hand is static (no independent movement) and limited to one of a small set of handshapes such as , , , (Battison, 1978; Eccarius and Brentari, 2006). These configurations are considered unmarked (less complex) (Battison, 1978; Sandler and Lillo-Martin, 2006)[3], while other hand configurations are considered marked (more complex).

Signs can also be phonologically more or less complex due to their syllable shape. Signed syllables can be defined by the types of movement used in a sign. Movement can consist of the hands moving from one location to another, describing a path movement. Path movement can be derived through changes in the position of the arm using the shoulder joint, and/or the elbow joint. Another kind of movement, known as local movement, involves hand position changes using the wrist joint,

3 The dominance condition just described is one criterion for identifying unmarked handshapes in ASL. Other diagnostics of unmarked properties include but are not limited to order of acquisition, accuracy in repetition, complexity in the phonological structure, frequency of occurrence in the lexicon (van der Kooij, 2002; Sandler and Lillo-Martin, 2006).

and/or changes in the hand configuration (e.g., closing from  to ; or opening from  to ), known as hand-internal movement. The vast majority of lexical signs are monosyllabic: they have at most one path movement (e.g., WEEK), or one local movement (e.g., MILKasym), or one path movement co-occurring with one local movement (e.g., THROW). More complex signs, with two (non-identical) sequential path movements (e.g., CENTER), or a path movement followed or preceded by a local movement (e.g., MAGIC), are rarely found in monomorphemic signs in ASL (Perlmutter, 1992; Brentari, 1998). More complex sequential movements that occupy more than one syllable are much less preferred than movement that occupies one syllable (Coulter, 1982; Liddell and Johnson, 1986; Sandler and Lillo-Martin, 2006).

In summary, phonological complexity for individual signs can be divided into two types: (a) simultaneous complexity (e.g., use of two hands or simultaneous movements); and (b) sequential complexity of disyllabic or multisyllabic signs (e.g., use of a sequence of non-identical movements). Given the affordances of the visual modality, simultaneous complexity may be more readily accommodated in sign languages than in spoken languages. Sign languages permit use of two hands, complex handshapes, and up to two types of movement in a single syllable, and they frequently combine morphemes into a single syllabic unit. On the other hand, sequential complexity is more common in spoken languages than in sign languages. Many spoken languages use words with complex sequential syllabic patterns not found in sign languages. We will return to discussion of these points in Section "Modality effects on complexity."

## Development of sign phonology

As mentioned above, studies of the phonological acquisition of sign languages by children have primarily focused on describing signs using parameter-based analyses. Analysis of spontaneous production data from a variety of sign languages has revealed a consistent developmental pattern whereby location and (when included in analysis) orientation are controlled earlier than movement and handshape (Conlin et al., 2000; Morgan et al., 2007; Karnopp, 2008; Takkinen, 2008). Various factors potentially contribute to this hierarchy of relative parameter difficulty for signing children. For instance, the inventory of handshapes employed by sign languages is generally quite large compared to the inventory of locations. Contrastive handshapes are often distinguished by small differences in finger selection or position that young children do not yet possess the fine motor skills to manipulate. Conlin et al. (2000) note that in addition to a high error rate, handshape in early signing is also subject to a high degree of variability, sometimes even within a single filming session. **Figure 2** shows four different handshape substitutions they illustrate for the target  handshape of the ASL sign FATHERstr by a deaf child between 8–11 months of age.

Finally, some researchers have reported that young children are able to produce and recognize handshapes much earlier in isolation (e.g., as individual fingerspelled letters) than combined with a location and movement as part of a lexical sign (Siedlecki and Bonvillian, 1997), and even after they have mastered a given handshape in lexical signs, they may continue to make errors with that same handshape in the context of classifier constructions (Kantor, 1980).

In comparison with forming one's hand into specific handshapes, moving the hands to a particular location of the body (e.g., the cheek versus the chest) demands much less precision and can thus be achieved by very young children (Siedlecki and Bonvillian, 1993). Of course, this does not mean that sign locations are uniformly target-like in early signing. Morgan et al. (2007) note that size of the target location affected accuracy for the British Sign Language (BSL)-acquiring subject they studied, who tended to replace relatively small target locations (e.g., the temple or the neck) with larger nearby locations (e.g., the cheek or the chest). Alternatively, location errors may be influenced by the saliency of the target location rather than its size, as suggested by Conlin et al. (2000) and Marentette and Mayberry (2000) for ASL, e.g., signing TELEPHONE at the ear rather than at the cheek. Under this account, some locations used by the child's sign language are not yet included in their developing body schema (perhaps those for which the child does not yet have a label, e.g., "cheek" or "temple") and thus are temporarily unavailable as locations for signs. Another characteristic location error pattern that has been reported by multiple researchers affects signs that require the hand to reach across the midline of the body. Bonvillian and Siedlecki (1996) and Conlin et al. (2000) report that for ASL signs such as BEAR, which requires both hands to cross and make contact with the opposite (contralateral) side of the torso, children avoid crossing the midline and instead contact the same (ipsilateral) side of the torso.

Movement accuracy in native signing children's spontaneous production is often reported as falling somewhere between location and handshape accuracy (Siedlecki and Bonvillian, 1993; Conlin et al., 2000). Meier et al. (2008) attribute a large proportion of these movement errors to limitations in the child's motor skills. For instance, they argue that the challenges of coordinating paired articulators are reflected in young children's production of mirroring errors, in which signs that require the two hands to assume different handshapes and/or movements are instead produced with the same handshape and/or the same movement. Meier et al. (2008) also report that children appear to avoid two-handed signs with differing handshapes and/or movements (e.g., MEANING), noting that they occur with high frequency in adult ASL but are strikingly under-represented in deaf children's spontaneous signing. Another movement error related to motor control is

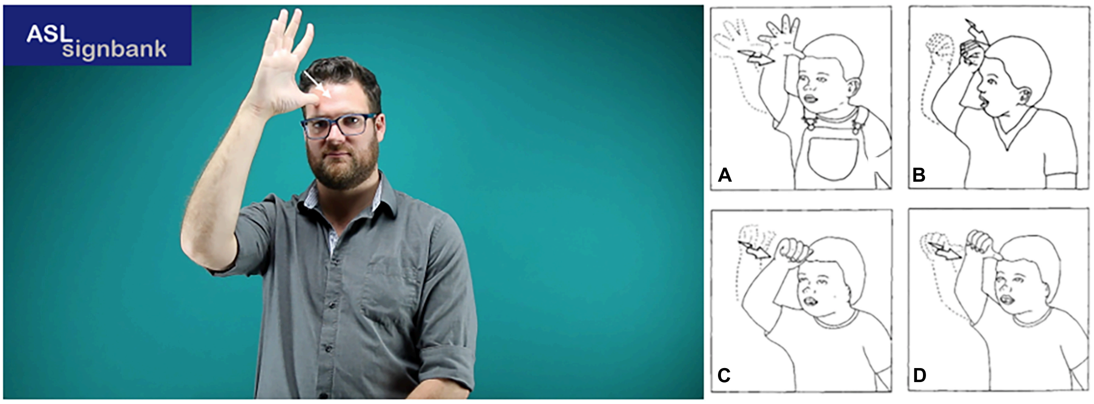


FIGURE 2
Handshape substitution errors produced by an ASL-acquiring child. **(Left)** Target form FATHERstr (reproduced with permission from ASL Signbank; Hochgesang et al., 2021). **(Right)** Child forms **(A–D)** [Copyright (2020) From Conlin et al. (2000: p. 60). Reproduced by permission of Taylor and Francis Group, LLC, a division of Informa plc].

proximalization, or modification of the joints used to produce sign movement from those farther away from the torso (e.g., knuckles and wrist) to those more proximal to the body (e.g., elbow and shoulder). For instance, the ASL sign FATHERstr in **Figure 2** (left) involves movement originating from the elbow joint. However, the child production illustrated in **Figure 2A** shows the movement from not only the elbow, but also the shoulder, a more proximal joint. Other instances of proximalized movement involve substitution of more proximal joints for less proximal joints, or in signs featuring multiple active joints, omission of more distal joints. These patterns are also attested in adult L2 signing and in child-directed signing (Holzrichter and Meier, 2000; Mirus et al., 2001).

Analyses of children's spontaneous signing report that path movement is generally controlled earlier than hand-internal movement (Cheek et al., 2001) and signs that call for both path and internal movement at the same time are particularly challenging. Morgan et al. (2007) observe that the deaf child subject they studied (ages 19–24 months) modified the movement feature in roughly half of the signs she attempted, through (a) substituting a different path (circular movements were especially error-prone), (b) omitting, proximalizing, or substituting a sign's internal movement, or simplifying signs that include both path and internal movements (mostly by deleting the path or internal movement, or by producing them sequentially rather than simultaneously).

The L1 sign language studies summarized here do not explicitly investigate the effect of sign complexity on acquisition, but we can deduce that some of the types of phonological complexity described in Section "Phonological complexity in sign languages" adversely affect the accuracy of children's production of certain parameters and/or the overall sign. For instance, Meier et al. (2008) report that ASL-signing children of 8–17 months produced sympathy errors, which occur when the non-dominant hand unexpectedly copies the movement of the dominant hand. Such errors can be regarded as a reaction to the relative complexity of two-handed asymmetrical signs. Similarly, the observation that the same handshapes may be produced more accurately in isolation than in the context of a lexical sign or classifier construction suggests that the "added demands of simultaneously producing location and movement aspects may [make] the task of correct handshape formation too difficult" (Siedlecki and Bonvillian, 1997, p. 34). Finally, detailed error figures reported by Morgan et al. (2007) indicate an adverse effect of complexity on movement accuracy. They report that the child subject they studied (age 19–24 months) displayed errors in 100 of the 118 (85%) attempted BSL signs featuring simultaneous path and internal movement; this proportion of errors is much higher than for signs with either path or internal movement in which the path was incorrect (45% errors), or the internal movement was incorrect (46% errors).

## Studies of phonology using pseudoword/pseudosign tasks

A common method for assessing phonological processing skills in children is the use of non-word repetition tasks, also known as pseudoword tests. In English, two commonly used tasks are Children's Test of Non-word Repetition (CNRep) (Gathercole and Baddeley, 1989) and the English Non-word Repetition Task (NRT) (Dollaghan and Campbell, 1998). These tests present children with novel words that are phonotactically permissible yet meaningless in their target language. Children hear and then reproduce the stimuli as accurately as possible, recalling the phonological form without relying on prior lexical knowledge. These tests for spoken language can be used to assess accuracy at the whole word level, and at the segmental level (consonants and vowels), as well as for various parameters at the suprasegmental level (stress, syllable, and tone).

Assessments using these tasks report a general trend for age of participants and length of pseudowords. Older children perform better than younger children, and shorter items are produced with higher accuracy than longer items (Chiat, 2006). This length effect has been found in English (Gathercole et al., 1994; Weismer et al., 2000; Thal et al., 2005), and other languages such as Brazilian Portuguese (Santos et al., 2006), Spanish (Ebert et al., 2008), Korean (Lee et al., 2013), Swedish (Sundström et al., 2014), French (dos Santos and Ferré, 2018), and Vietnamese (Pham et al., 2018). While some studies only include words of two or more syllables, others have found that when one-syllable words are included in the stimuli, such as the NRT, which consists of one- to four-syllable pseudowords in English, one-syllable and two-syllable words were produced with a similar accuracy level, with accuracy dropping only from three syllables upward by typically developing children (Gathercole et al., 1994; Weismer et al., 2000; Thal et al., 2005).

In the same vein as these spoken language tasks, sign-based non-word repetition tasks have also been developed following the same principles. Researchers have used pseudosign tasks to study the acquisition of British Sign Language (BSL) (Mann et al., 2010), Brazilian Sign Language (Libras) (Quadros et al., 2014), American Sign Language (ASL) (Cruz et al., 2014; Kozak, 2018), French Sign Language (LSF) (Cristini and Bogliotti, 2015); and with adults using Sign Language of the Netherlands (NGT) (Klomp, 2015; Vink, 2018). These tasks present phonotactically permissible but meaningless signs to participants, who then repeat them as accurately as possible. These tasks focus on the parameters of handshape, location, movement, and some include orientation as well.

In these tasks, it has generally been found that location is the most accurately reproduced parameter, and handshape is the least accurate. Furthermore, unmarked handshapes and simple movements (internal or path) are more accurately reproduced than marked handshapes and complex movements (which combine path movements with hand-internal movements and/or orientation change).

While these tasks are most commonly run unimodally, there have been studies comparing bimodal bilingual children's phonological abilities on the non-word repetition tasks in both modalities; for American children as well as Brazilian children, finding a positive correlation for scores between spoken and signed modalities (i.e., English and ASL, or Brazilian Portuguese and Libras) (Cruz et al., 2014; Kozak, 2018).

# Materials and methods

## Materials

The ASL-based pseudosigns were developed following criteria described by Mann et al. (2010). Our task consisted of 39 nonsense signs that conform to the dominance and symmetry conditions of ASL (Battison, 1978) which constrain the possible forms between the two hands. The stimuli were developed by a group of deaf and hearing researchers, all native or fluent ASL signers (Quadros et al., 2015). The internal structures of the pseudosigns ranged from simple to complex in form, comprising eleven possible sign configuration categories, shown in **Supplementary Table 1A**. These pseudosigns were signed by a deaf native signer against a plain blue backdrop to create the video stimuli[4]. Test items were randomized and separated by a fade to black, during which participants were instructed to copy the pseudosign they had just seen.

For this study, we regrouped the 39 pseudosigns according to the following three variables: number of hands, simultaneous movement combinations, and movement sequence.

(i) Number of hands: the stimuli were classified into one-handed signs ($N = 18$) and two-handed signs ($N = 21$), which include symmetrical signs ($N = 15$) and asymmetrical signs ($N = 6$).

(ii) Movement combinations: the stimuli were classified according to the number of simultaneous movement types. Three categories were identified: (i) only one movement type, either (a) path movement or (b) handshape/orientation change ($N = 20$)[5]; (ii) two simultaneous movement types (path movement plus handshape change, or path movement plus orientation change) ($N = 11$); (iii) three simultaneous movement types (path movement, orientation change, and handshape change) ($N = 8$).

(iii) Movement sequence: the stimuli were grouped into (i) signs that involve a movement sequence, i.e., a combination of two successive path directions or path movement plus hand-internal movement ($N = 3$); and (ii) signs that contain no movement sequence, i.e., no successive path movements ($N = 36$). Note that items with repetitive path movement or oscillation[6] were counted as occupying only one syllable or one movement in the phonology, even though temporally they contain multiple movements and are phonetically not short (Jantunen, 2015). They can co-occur with other types of movement in the same temporal span (Brentari, 1998; Jantunen and Takkinen, 2010; Sandler, 2017), so for

4 The ASL pseudosign stimuli videos can be found at this link: https://slla.lab.uconn.edu/wp-content/uploads/sites/1793/2019/02/ASL-pseudosign-stimuli-random-SLLA.mov.

5 In this study, handshape change contributes to movement complexity as in the Prosodic Model (Brentari, 1998, 2019). Meanwhile, as discussed at the end of Section "Materials," following Brentari et al. (2017), in the calculation of the complexity of the handshape parameter *per se*, we included the dynamic aspects so that an extra point is added if there is a change in joint position, and another extra point if there is a change in selected fingers.

6 According to Brentari (1998), repetition refers to a movement that is repeated; oscillation (also called trilled movement) refers to an uncountably repeated movement.

this reason, they were counted in the "no movement sequence" category. Signs having no movement sequence are considered to occupy a single syllable, while signs having a movement sequence, i.e., more than one non-identical movement in sequence, correspond to two syllables in the prosodic structure (Brentari, 1998; Wilbur, 2011).

The combinatorial possibilities of the three complexity variables are twelve (i.e., 2*3*2), although only eight combinatorial options were included in our stimuli. For instance, we did not design any one-handed or two-handed pseudosigns that both involve three simultaneous movement types and contain a movement sequence. Even if actual signs with such phonological structures exist, they are rarely attested and are thus very marginalized in the ASL lexicon. Also, one-handed pseudosigns with two simultaneous movement types, and two-handed pseudosigns with only one movement type were not included, although such gaps did not affect the overall results and patterns we propose in this paper. The eight combinatorial possibilities covered by the stimuli are provided in **Table 1**.

We provide illustrations of four pseudosigns as examples of our stimuli in **Figure 3**.

Apart from the three complexity variables above, a scale of handshape complexity was employed to examine possible associations between performance and handshape complexity. Handshape complexity was determined based on criteria developed by Eccarius and Brentari (2008) and Brentari et al. (2017), as described below.

Joint position and finger selection were assigned separate complexity scores. Joint position complexity scores of 1 (low) and 2 (medium) were given to shapes with fully open/closed fingers, and flexed fingers, respectively. The possible high complexity score of 3 was irrelevant to this study since our stimuli did not involve any joint positions like the  handshape or crossed fingers. Finger selection complexity scores of 1 (low) were assigned to selection of either all/no fingers or selection of index and/or thumb, 2 (medium) to pinkie finger or both index and middle fingers, and 3 (high) to other finger selections. A handshape was assigned an extra point each for involving change in joint position and change in finger selection, the former occurring in handshape contours and the latter in handshape contrast.

Brentari et al. (2017) did not discuss the complexity score of handshapes in two-handed signs. In our calculation of handshapes in two-handed pseudosigns, no extra points were assigned if the handshapes of the two hands were identical, but we added one extra point to two-handed pseudosigns in which the handshapes of the two hands were different.

Handshapes of various complexities were evenly distributed among the stimuli, so we do not consider classification of pseudosigns according to handshape complexity in **Table 1**. Further, handshape complexity was indexed as a continuous variable in this study whereas the other three variables were categorical variables, with each dividing the stimuli items into two or three groups in **Table 1**.

## Participants

Participants were 22 children (ages: 4;0–8;10, $\bar{x}$ = 6;04, *SD* = 1;02) acquiring ASL as an L1 from Deaf parents[7]. Six were deaf ($\bar{x}$ = 6;11, *SD* = 1;7), 3 deaf with cochlear implants (referred to as DDCI hereafter; $\bar{x}$ = 5;07, *SD* = 0;1), and 13 hearing (referred to as kodas, or kids of deaf adults; $\bar{x}$ = 6;03, *SD* = 1;0). Because all children were born into signing Deaf families, they were exposed to ASL from birth.

## Procedure

The test was run by native signers of ASL. Participants were told that they were going to see some silly signs and should try to copy them as well as they could. There were two unscored trial pseudosigns after the instructions, followed by the 39 target pseudosigns. Participants saw and reproduced the pseudosigns in a sitting position. All test items were shown only once, except in cases where a participant became distracted and missed an item.

## Scoring

The first author scored all 39 pseudosigns for accuracy at the feature level. During scoring, we encountered some sign reproductions that deviated from the target form in very subtle ways, and it was difficult to determine what degree of deviation counted as an error. Such challenges have also been reported by other researchers in scoring real signs reproduced by L2 signers (Willoughby et al., 2015; Ebling et al., 2021). To unify the scoring criteria and make a clear distinction between 'errors' and 'distortions' or acceptable deviations, we consulted two deaf researchers at Gallaudet University and discussed their intuitions on acceptable and unacceptable variations in thumb position, orientation and handshape of the non-dominant hand,

7 All the deaf children in our current study were raised in the Deaf community and are users of a natural sign language (ASL). Previous publications (including many of our own) used the capitalized term "Deaf" to designate individuals who identify as culturally Deaf, and who by extension use sign language as a principal mode of communication. However, this convention is changing, and we recognize the problematic nature of assuming the cultural identity of participants in our research, including young children who may not have adopted the Deaf identity label for themselves. We thus refer to "deaf children" and "deaf researchers" in this paper, although we retain the terms "Deaf community" or "Deaf families".

TABLE 1 Combinatorial possibilities of complexity in the pseudosign stimuli.

| Category | Complexity variables | | | Number of items ($N = 39$) |
|---|---|---|---|---|
| | Number of hands (one, two) | Number of simultaneous movement types (one, two, three) | Movement sequence (yes, no) | |
| 1 | One | One | No | $N = 8$ |
| 2 | One | Two | No | $N = 6$ |
| 3 | One | Three | No | $N = 3$ |
| 4 | One | One | Yes | $N = 1$ |
| 5 | Two | One | No | $N = 11$ |
| 6 | Two | Two | No | $N = 4$ |
| 7 | Two | Three | No | $N = 4$ |
| 8 | Two | Two | Yes | $N = 2$ |

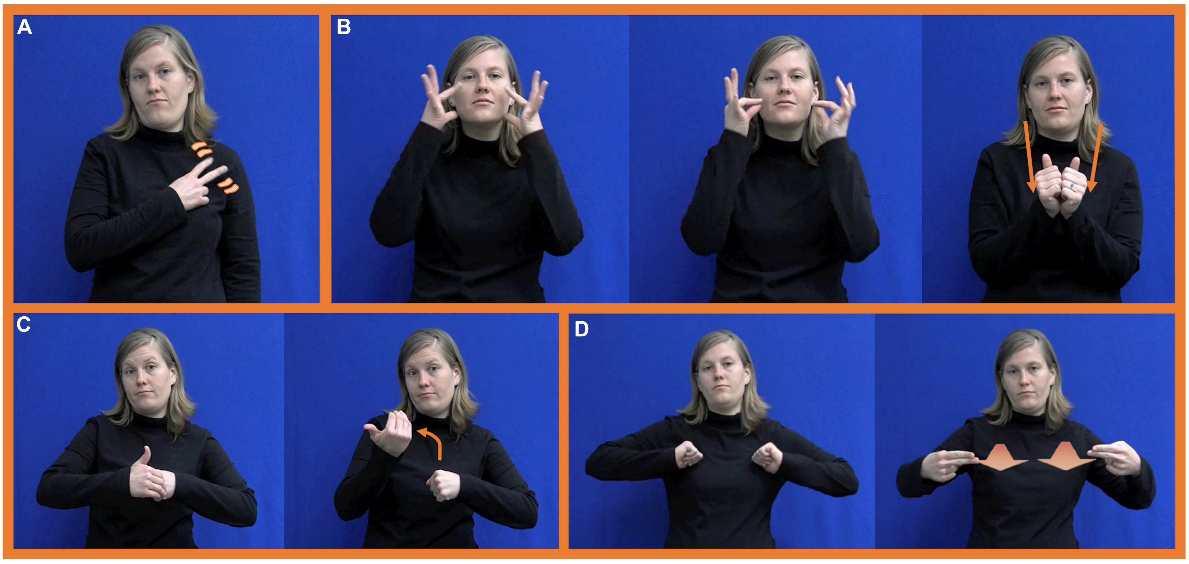


FIGURE 3
Still pictures of example pseudosign stimuli. **(A)** One hand, one movement type, no movement sequence (category 1). **(B)** Two hands, two simultaneous movement types, movement sequence (category 8). **(C)** Two hands, two movement types, no movement sequence (category 6). **(D)** Two hands, three simultaneous movement types, no movement sequence (category 7).

height in neutral space, and oscillation. Having incorporated the deaf researchers' judgments, the research team reached an agreement on the following scoring criteria at the feature level:

(1) Handshape: participants' sign handshapes were coded for three aspects: finger selection, joint position, and thumb. The reproduction of each property was scored 1 if correct and 0 if incorrect. For compound-like pseudosigns that involve two contrastive handshapes, i.e., two sets of selected fingers, the initial and final handshapes were separately coded. In two-handed pseudosigns, handshapes on both hands were also separately coded. The handshape on the dominant hand was coded in the same way as handshape in one-handed pseudosigns. The handshape on the non-dominant hand was coded holistically, i.e., scoring 1 if it was reproduced correctly and 0 if any of the three properties, namely finger selection, joint position, or thumb, was reproduced inaccurately. One-handed pseudosigns scored 3 points or maximally 6 points (if there were two contrastive handshapes). Two-handed pseudosigns scored 3 points for the dominant hand and 1 point for the non-dominant hand. In sum, a system of 4 points or maximally 8 points (if there were two contrastive handshapes) was used for handshapes in two-handed pseudosigns.

The following handshape errors were expected and identified: substitutions in finger selection, joint position, or thumb position; omission of handshape contrast (handshape contour that involves a change in selected fingers) which occurs when a reproduction involves a joint position change but fails to include a change of selected fingers; handshape assimilation of the non-dominant hand to the dominant hand. Reproductions of target handshapes with abducted fingers in which the fingers of the non-dominant hand were slightly splayed were not regarded as errors. Further, some slight deviations in the thumb position were not marked as errors. For instance, we coded as accurate instances where the thumb was slightly opposed (see **Figure 4A**, right), even though the thumb of the target form was fully unopposed, resting near the index finger (see **Figure 4A**, left). Other instances with more salient handshape deviations were marked as errors, such as the thumb being extended when it was closed/opposed in the target form.

(2) Location: participants' sign locations were coded according to the height/side for each pseudosign; for those signs that inherently contain body/hand contact, the contact property was also coded, worth one extra point. The reproduction of each property was scored 1 if correct and 0 if incorrect. In compound pseudosigns that involve two major locations, both the initial and final locations were coded. The location on the dominant hand in two-handed pseudosigns was coded in the same way as in one-handed pseudosigns, but the location of the non-dominant hand was coded holistically. One-handed pseudosigns produced in neutral space were scored up to 1 point for location. One-handed pseudosigns with body contact were scored up to 2 points, and two-handed pseudosigns with body or hand contact were scored up to 3 points. Finally, in pseudosigns involving two major locations, the points were doubled in coding for a maximum of 6 points.

Location errors include substitution of the ipsilateral for contralateral side, omission of body/hand contact, and substitutions in height on the face or torso. We accepted some deviations in the height of signs in neutral space. For instance, some signs were produced in locations that were raised or lowered compared to the target as an accommodation of signing in a sitting position, or while leaning on the table (see **Figure 4B**, right). Some pseudosigns reproduced higher than the target in neutral space were accompanied by exaggerated non-manual signals (e.g., head forward and shoulders hunched up) to look "silly" (see **Figure 4C**, right)[8]. Because height in neutral space is not lexically contrastive in ASL (McBurney, 2002), we coded these instances of raised or lowered spaces as acceptable variants of the target.

8 This example of a 'silly-looking' pseudosign production comes from a child whose data were not included in the currently analysis, but for whom we have permission to publish images.

(3) Movement: participants' sign movements were coded for the following four properties: direction, repetition, shape, and alternation. Movement repetition was coded if the pseudosign inherently involved repetitive movement or oscillation, worth one extra point. If the movement path was anything other than straight, that movement trajectory/shape was coded, also worth one extra point. For pseudosigns that involve a movement sequence, the first and second movements were separately coded. Movement of the dominant hand in two-handed pseudosigns was coded in the same way as in one-handed pseudosigns. Movement of the non-dominant hand was coded holistically. In two-handed alternating pseudosigns, alternation was coded as an additional property of movement, adding one extra point. Finally, directions in path movement, handshape change, and orientation change were coded separately depending on the number of simultaneous movement types in the pseudosigns. Given that some two-handed pseudosigns contain as many as three simultaneous movement types, we did not collapse all movement properties into one point in the coding of the non-dominant hand, as we did for other parameters. 1 point was assigned to each type of movement (path movement, handshape change, or orientation change) on both hands if produced correctly, and 0 points were assigned if the property in question was produced incorrectly or completely lost.

Movement errors include omission or substitution of movement direction (handshape change, path movement, and orientation change), omission of repetition, and addition of unexpected movement. The deaf researchers we consulted were especially sensitive to differences in movement, particularly path movement, and hence a stricter standard on path movement was set. In contrast, the deaf researchers regarded children's slower oscillation in response to signs featuring rapid alternations between fingers as completely acceptable. For targets with oscillating movement, we thus coded slowed repetitive finger movement as an acceptable variant, but failure to alternate fingers was still coded as a movement error.

(4) Orientation: participants' sign orientation was coded for two properties: palm orientation and fingertip facing (i.e., orientation of the leading edge of the fingers). In one-handed pseudosigns, 1 point was awarded for orientation of the palm if it was reproduced correctly and 0 points if not. In a similar vein, 1 point was awarded for correct orientation of fingertips. In two-handed pseudosigns, accuracy was worth 3 points in total, with the dominant hand being assigned 2 points and the


FIGURE 4
Target form and child form. **(A)** Thumb position; **(B)** height in neutral space; **(C)** height in neutral space; and **(D)** fingertips orientation of the non-dominant hand.

non-dominant hand 1 point[9]. If the pseudosigns involved an orientation change, both the initial and final orientations were scored independently.

Orientation errors were identified in substitution of the hand parts (radial, ulnar, palm, fingertips, back, and wrist) that contact certain body parts or the non-dominant hand. Deviations in orientation in neutral space were more acceptable to the deaf researchers we consulted and hence not regarded as errors unless the deviations are very salient. For instance, we observed many deviations in the fingertip orientation of the non-dominant hand. In one item, the fingertips point forward in the target, with the palm facing the side. Many children copied the item by positioning their non-dominant hand with fingertips pointing upward (see **Figure 4D**, right) rather than outward as in the target (see **Figure 4D**, left). The deaf researchers judged this subtle deviation as non-critical and arguably not erroneous as long as the palm was facing in the correct direction, i.e., to the side. But if the fingertips of the non-dominant hand pointed inward rather than outward, as observed for one child, this deviation was far more salient and was judged by our consultants as 'awkward' and not acceptable.

Overall accuracy for each pseudosign was calculated by dividing the total points earned for correctly reproduced features by the maximum possible number of points for that sign. Feature scores related to the same parameter were averaged to calculate composite accuracy scores for the individual parameters.

As a reliability check of our scoring system, the third author independently scored at the parameter level. We sampled 20% of the reported data (all 39 pseudosign reproductions from one deaf, one DDCI, and two koda participants). To render the scoring results between the two raters comparable, feature scores related to the same parameter were converted to binary scores of 0 and 1, with 0 indicating no parameter errors (i.e., 100% accuracy under the feature-based scoring approach) and 1 for parameter errors (i.e., <100% accuracy under the feature-based scoring approach). The inter-rater agreement for location, handshape, orientation, and movement was 90, 88, 87, and 86%, respectively.

## Results

The performance of each participant was measured by accuracy in the reproduction of pseudosigns. We examined both overall accuracy and individual parameter accuracy. Complexity was measured by four variables:

9 One reviewer suggested investigating accuracy in the symmetrical orientation and identical orientation between the two hands in two-handed signs. Participants in this study rarely made errors on orientation between the two hands. Further, the authors found that this distinction between symmetrical orientation and identical orientation in two-handed signs does not play a role in the contrast this study is focusing on, namely simultaneous versus sequential complexity.

number of hands (two-handed vs. one-handed), movement combinations (less than three simultaneous movement types vs. three simultaneous movement types), presence of movement sequence (movement sequence vs. no movement sequence), and handshape complexity. We will report results from both univariate analysis and multivariate logistic regression models.

## Overall accuracy

The overall accuracy on the pseudosign repetition task across all 22 children averaged 91.4% (*SD* = 11.2%) The average accuracy was 96.0% (*SD* = 7.3%) in the deaf group (*N* = 6), 91.4% (*SD* = 10.0%) in the DDCI group (*N* = 3) and 89.3% (*SD* = 12.2%) in the koda group (*N* = 13).

Regarding performance on signs with various degrees of complexity, we compared the accuracy score by number of hands, number of simultaneous movement types, and movement sequence, as shown in **Table 2**.

In **Table 2**, it can be seen that the pseudosigns involving a movement sequence scored among the lowest for accuracy (86.3% for items with two hands, two simultaneous movement types, and 87.7% for the item with one hand, a single movement type) and showed the greatest variability in accuracy. Further, among the pseudosigns with no movement sequence, pseudosigns with three simultaneous movement types had lower accuracy scores (86.6% for one-handed items and 88.9% for two-handed items) than those with one or two movement types (accuracy above 92.5%). Finally, no clear difference in accuracy was seen between one-handed and two-handed pseudosigns.

We divided complexity into two dimensions: simultaneous and sequential. Simultaneous complexity is displayed by number of hands (two-handed vs. one-handed) and number of simultaneous movement types (three, two or no simultaneous movement). Sequential complexity is manifested by the presence of a movement sequence (movement sequence vs. no movement sequence). In **Figure 5**, the average accuracy is compared across several complexity measures. The (non-)overlapping confidence intervals in **Figure 5** indicate that some complexity measures were found to influence the overall accuracy, but some others were not. We found a significant difference in overall accuracy between signs with three simultaneous movement types and signs with one or two simultaneous movement types, although the overall accuracy in items with one movement type and two simultaneous movement types did not significantly differ. The items that involve a movement sequence had a significantly lower accuracy compared with items with no movement sequence. Finally, the overall accuracy difference between two-handed and one-handed items was not significant.

We also found a univariate association of age with the overall accuracy (intercept = 0.78, slope = 0.02, $p < 0.001$), as shown in **Figure 6**. This suggests that performance improved as age increased.

## Parameter accuracy

To obtain accuracy of each individual parameter, we averaged the feature scores related to the same parameter to calculate composite scores. In order to make our results comparable to other studies on sign phonological development, which predominantly used parameter-based scoring (see Section "Development of sign phonology"), we also calculated the parameter scores based on the less granular binary method. That is, we scored the production either as accurate (i.e., no errors in the production of this parameter) or as inaccurate (i.e., at least one error in the production of this parameter). The results of individual parameter accuracy, accuracy range, and number of errors from the two scoring methods are provided in **Table 3**.

We predicted that the feature-based scoring method would yield relatively higher scores and lower variability than the parameter-based scoring method. The results in **Table 3** show that this prediction was borne out. As introduced in Section "Scoring," feature-based scoring provided more opportunities for participants to earn points for accurate reproduction of the various features under each parameter. Thus, accuracy is relatively high, and variability is low, indicated by the results of higher average accuracies and narrower accuracy range in feature-based scoring compared to parameter-based scoring.

In terms of number of errors, more errors occurred in handshape, followed by movement, location, and orientation in feature-based scoring. Further, feature-based analysis could capture multiple errors within each parameter, which were obscured under parameter-based scoring. Regarding accuracy score, movement was produced least accurately, followed by handshape, location, and orientation, based on feature-based scoring. Overall patterns were similar to the results of parameter-based scoring except that movement performance was better under parameter-based scoring, coming in as the second most accurate after the orientation parameter. The increased accuracy in movement could be ascribed to the fact that as shown in **Table 3**, the number of movement errors as well as handshape errors drastically decreased when switching from feature-based scoring to parameter-based scoring method. Combining accuracy scores and number of errors based on feature scoring, we found that location and orientation were produced more accurately than movement and handshape, in line with the literature on phonological accuracy in naturalistic production discussed in Section "Introduction."

We performed univariate regression models to analyze the association between individual parameter accuracy and age. After Bonferroni correction, increased age was found to be associated with better performance for almost all the

TABLE 2 Accuracy in signs that vary by number of hands and movement combinations (simultaneous and sequential).

| Pseudosign complexity (number of hands * number of simultaneous movement types * number of movement sequence) | Avg. accuracy (*SD*), % |
|---|---|
| One-handed, one movement type, no movement sequence (*N* = 8) | 92.9 (3.8) |
| Two-handed, two simultaneous movement types, no movement sequence (*N* = 4) | 92.7 (5.7) |
| One-handed, two simultaneous movement types, no movement sequence (*N* = 6) | 92.5 (6.1) |
| Two-handed, one movement type, no movement sequence (*N* = 11) | 92.5 (6.0) |
| Two-handed, three simultaneous movement types, no movement sequence (*N* = 4) | 88.9 (9.1) |
| One-handed, one movement type, movement sequence (*N* = 1) | 87.7 (15.7) |
| One-handed, three simultaneous movement types, no movement sequence (*N* = 3) | 86.6 (6.7) |
| Two-handed, two simultaneous movement types, movement sequence (*N* = 2) | 86.3 (11.6) |

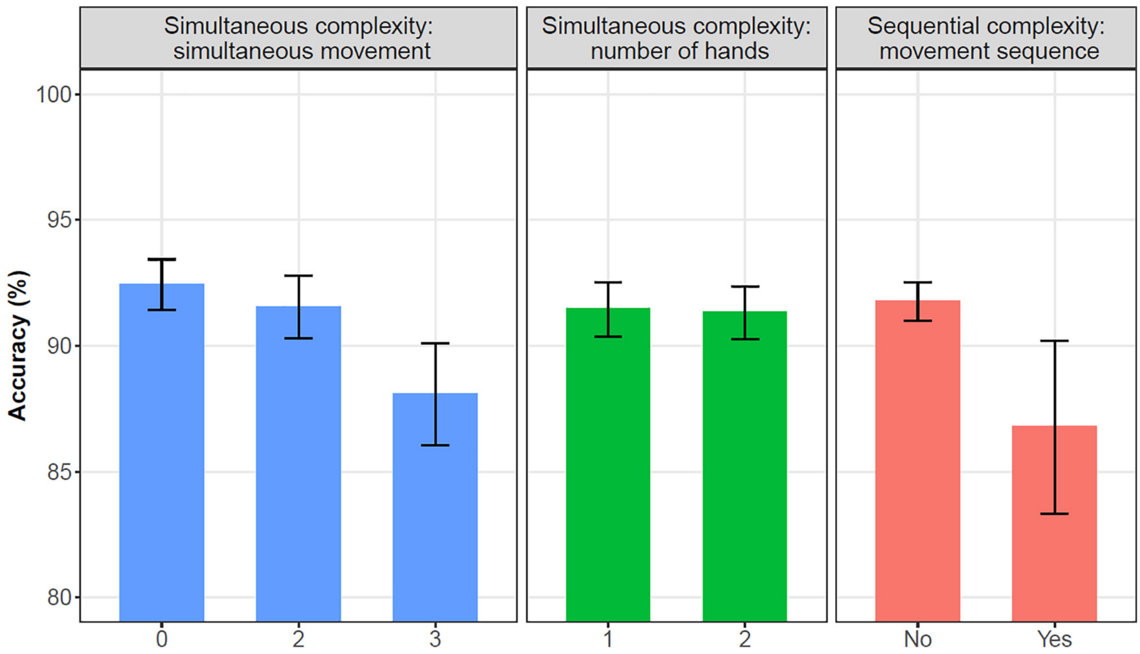


FIGURE 5
Overall accuracy (average across 22 participants) in items with differing simultaneous and sequential complexities, with 95% confidence intervals.

parameters (location: intercept = 0.770, slope = 0.024, $p < 0.01$; orientation: intercept = 0.817, slope = 0.018, $p < 0.01$; movement: intercept = 0.666, slope = 0.037, $p < 0.01$) although the association between age and handshape accuracy was not statistically significant (intercept = 0.924, slope = 0.013, $p = 0.24$). These results of univariate association between parameter accuracy and age are provided in **Figure 7**. The lines are fitted by univariately regressing accuracy scores on age.

In addition, as discussed in Section "Materials," we examined the scoring of complexity for the handshape parameter (complexity score range: 2–6). A significant association was found between accuracy in handshape parameter and handshape complexity ($p = 0.001$). In **Figure 8**, the handshape complexity is slightly jittered to separate points and the line is fitted by univariately regressing handshape accuracy scores on handshape complexity. In addition, no significant association emerged between overall accuracy of the item and handshape complexity ($p = 0.486$).

## Multivariate analysis

Many of the factors we considered in this study can be correlated. For example, children in the deaf group are older than those in the other two groups, which could have given them an advantage on this task. Also, the different complexity measures of the items may also depend on each other. We thus conducted a multivariate analysis to jointly analyze the effects of each factor on the accuracy scores. We performed logistic regression with participant and item level random effects

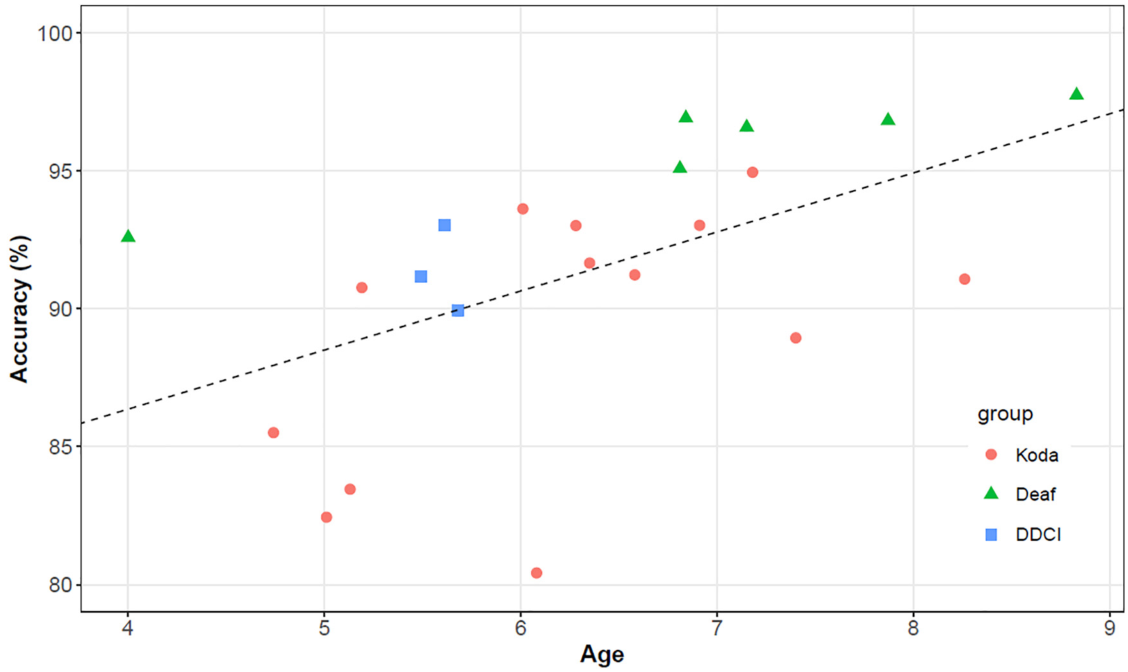


FIGURE 6
Overall accuracy and its relationships to age (intercept = 0.778, slope = 0.021, $p < 0.001$).

TABLE 3 Accuracy, accuracy range, and number of errors distributed in each parameter.

| Parameters | Feature-based scoring | | | Parameter-based scoring | | |
|---|---|---|---|---|---|---|
| | Avg. accuracy (*SD*), % | Accuracy range, % | Number of errors | Avg. accuracy (*SD*), % | Accuracy range, % | Number of errors |
| Orientation | 93.1 (3.5) | 86.3 – 98.3 | 220 | 82.8 (8.2) | 69.2 – 97.4 | 147 |
| Location | 92.1 (5.0) | 81.1 – 99.4 | 228 | 79.3 (11.8) | 56.4 – 97.4 | 177 |
| Handshape | 90.6 (6.0) | 74.1 – 96.8 | 374 | 74.0 (12.6) | 43.6 – 89.7 | 222 |
| Movement | 90.0 (6.8) | 75.6 – 97.9 | 278 | 81.0 (11.2) | 56.8 – 94.9 | 162 |

to analyze the association between accuracy scores and sign complexity, adjusting for age and group (koda, deaf, and DDCI). Phonological complexity for pseudosigns was measured by four variables: two-handed vs. one-handed (number of hands), three vs. two or no simultaneous movement type, movement sequence vs. no movement sequence, and handshape complexity. Logistic regression with binomial distribution was used to model the number of errors out of the total points in each pseudosign. The performance of a participant was measured by the errors of location, handshape, movement, and orientation. The model specification is provided in the Supplementary material shared on OSF. All the analyses were conducted using R software (R Core Team, 2021) and package lme4 (Bates et al., 2015).

Table 4 shows the result of the regression analysis. The odds ratios (OR, meaning the ratio of probability of making an error to the probability of not making an error), 95% confidence intervals (CI) and *p*-values are provided. An OR < 1 means the factor is associated with fewer errors and thus better overall performance. The following factors are significantly associated with better overall performance, with *p*-values less than 0.05: older age, being deaf, two or no simultaneous movement type, and no movement sequence. In contrast, the accuracy difference between two-handed and one-handed signs is not significant.

Within the two-handed items, we compared the two subtypes, i.e., symmetrical signs and asymmetrical signs. No significant difference in overall accuracy (OR = 0.684, *p*-value = 0.210) was found between the production of these two subtypes. Details of multivariate analysis of accuracy in symmetrical signs and asymmetrical signs are provided in **Supplementary Table 1B**.

We also tested whether there is interaction between the complexity variables. Since some of the combination of complexity measures were not available in the pseudosign items, we were only able to test the interaction between

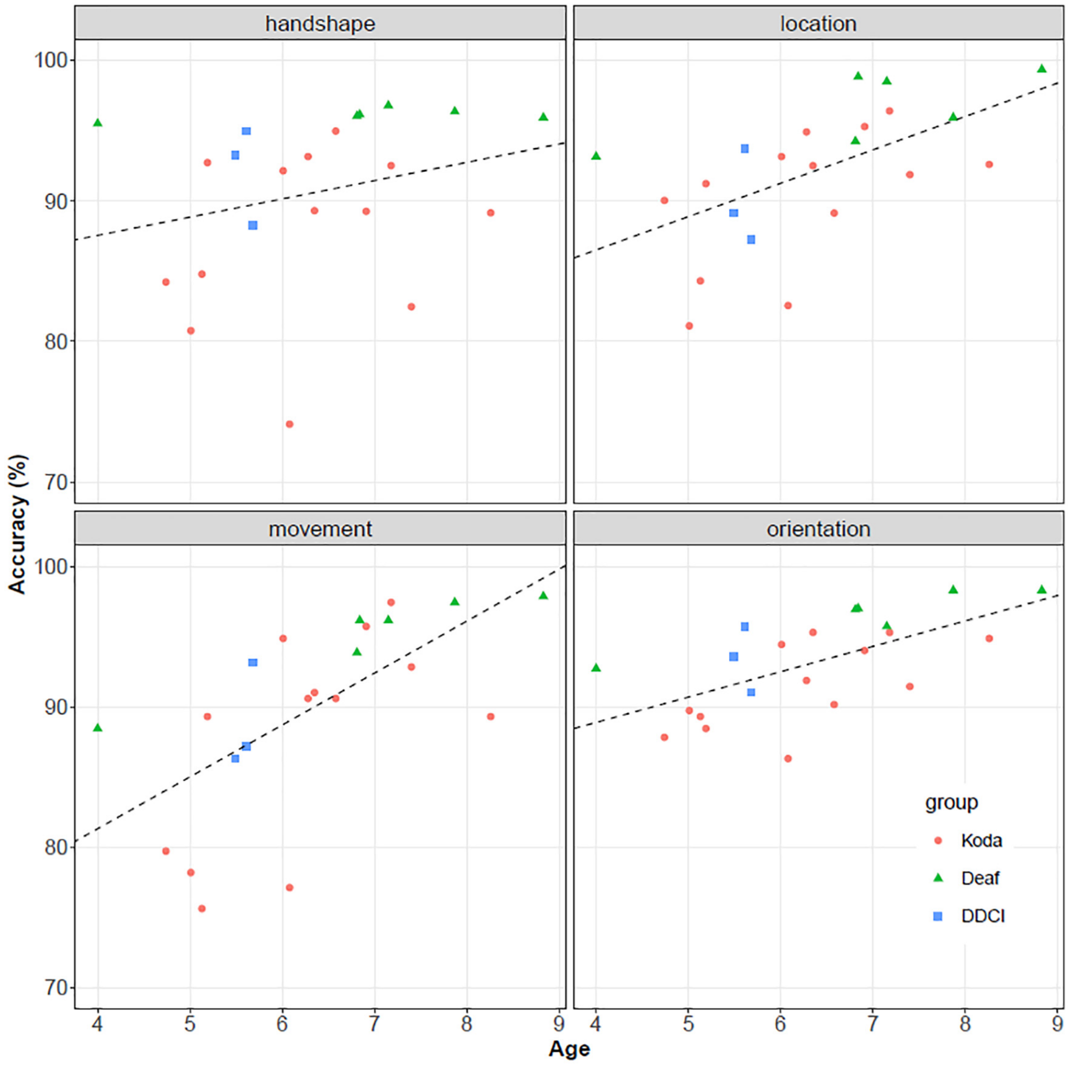


FIGURE 7
Individual parameter accuracies and their relationships to age.

handshape complexity and number of simultaneous movement types/movement sequence/hands, and between number of hands and number of movement sequence/simultaneous movement types. The interaction effects were not found to be statistically significant, as indicated in Supplementary Table 1C. That is, no significant interaction between two-handedness and three simultaneous movement types or movement sequence was found. No significant interaction was found between handshape complexity and the other three complexity measures. Based on the goodness of fit of the interaction model (i.e., the Akaike Information Criteria of the interaction model is greater than that of the main effect model), we conclude there is no interaction between complexity measures on the overall accuracy and therefore base our major findings on the main effect model reported in Table 4.

Regarding handshape, although handshape complexity is associated with handshape accuracy as reported in Section "Parameter accuracy," no significant association was found between handshape complexity and overall accuracy of the item or performance on other parameters (movement, location, and orientation), as indicated in Table 5. With respect to effects of other parameters, Table 5 shows that the association between lower accuracy on orientation and having three simultaneous movement types is statistically significant ($p = 0.014$). The associations between the complexity measures (number of hands, number of simultaneous movement types, and number of movement sequence) and movement parameter accuracy are relatively strong, from which only movement sequence is statistically significant ($p < 0.001$). An elaborate version of Table 5 which contains the 95%

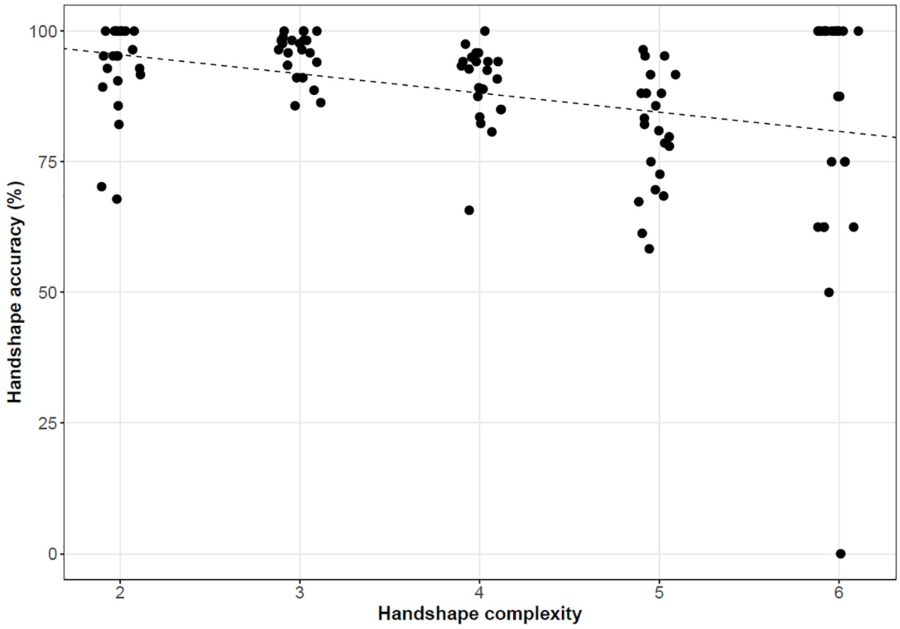


FIGURE 8
Handshape parameter accuracy and its relationships to handshape complexity (intercept = 1.029, slope = 0.027, $p$ = 0.001).

confidence intervals and $p$-values is provided in **Supplementary Table 1D**.

## Discussion

This study investigated ASL-signing children's phonological development using a pseudosign repetition task. It also examined possible relationships between accuracy in pseudosign repetition, age, and complexity in multiple dimensions. Through these investigations, we are able to comment on potential modality-based differences between phonological development in signed and spoken languages.

Previous studies examining performance on a variety of tasks have found slightly different patterns of accuracy across the four parameters. The ranking of parameters by observed accuracy can vary due to differences in task (perception/discrimination and production), stimuli complexity, and participants [children vs. adults; L1 signers vs. L2 signers vs. non-signers; as reported by Conlin et al. (2000), Mirus et al. (2001), Emmorey et al. (2009), and Mann et al. (2010)]. Here, we focus on comparing our results with general patterns reported in other studies of phonological development.

### Phonological development

In the current study, accuracy among the 22 ASL-signing children (mean age: 6;04) in the pseudosign repetition task was good, with an average of 91.4%. As indicated in **Figure 5**, overall, repetition accuracy increased with child age, echoing the results of other child pseudosign repetition tasks (Marshall et al., 2006; Mann et al., 2010; Cruz et al., 2014; Koulidobrova and Ivanova, 2020).

We also found that performance on individual parameters (handshape, location, movement, and orientation) increased with age, as shown in **Figure 6**, although the association between performance in handshape parameter and age was not significant. This somewhat surprising result can probably be explained by the fact that younger-aged children are already performing relatively well in handshape. A closer look at individual participants revealed that one koda participant underperformed with respect to their age. Given our relatively small sample size (22 children), a single outlier score could have a disproportionate effect on the distribution of the scores across all participants. We leave this for future research once a larger sample size can be guaranteed.

To examine signing children's development patterns, we examined pseudosign accuracy for individual parameters. Our results revealed that movement and handshape were less accurately produced than location and orientation. These findings are consistent with accuracy patterns reported for real signs produced by both L1 (Conlin et al., 2000; Marentette and Mayberry, 2000; Morgan et al., 2007) and L2 signers (Jissink, 2005; Chen Pichler, 2011; Ortega and Morgan, 2015; Ebling et al., 2021). In the next subsections, we examine additional evidence from both child and adult learners that corroborate

TABLE 4 Results of multivariate logistic regression of overall accuracy of the item on age, group, and complexity.

| Factor | Reference | OR | 95% CI | *P*-value |
|---|---|---|---|---|
| Intercept | n/a | 0.365 | (0.126, 1.053) | 0.062 |
| Age | 1 year | 0.761 | (0.665, 0.871) | <0.001 |
| Group: deaf | Koda | 0.358 | (0.248, 0.515) | <0.001 |
| Group: DDCI | Koda | 0.648 | (0.419, 1.001) | 0.051 |
| Handshape complexity | increment of 1 | 1.083 | (0.908, 1.292) | 0.376 |
| Complexity: 2-handed | 1-handed | 1.657 | (0.662, 1.383) | 0.815 |
| Complexity: simultaneous movement, three | Two or no | 2.208 | (1.149, 4.24) | 0.017 |
| Complexity: movement sequence | No movement sequence | 2.208 | (1.149, 4.249) | 0.017 |

TABLE 5 Association of each parameter accuracy with age, group, and item complexity measures.

| Factor | Reference | Location OR | Handshape OR | Orientation OR | Movement OR |
|---|---|---|---|---|---|
| Intercept | n/a | 1.309 | 0.032 | 0.249 | 1.327 |
| Age | 1 year | 0.723*** | 0.864 | 0.745*** | 0.648*** |
| Group: deaf | Koda | 0.348*** | 0.268*** | 0.388*** | 0.386*** |
| Group: DDCI | Koda | 0.811 | 0.480 | 0.685 | 0.613 |
| Complexity: handshape | Increment of 1 | 0.767 | 1.687*** | 1.003 | 1.015 |
| Complexity: 2-handed | 1-handed | 0.773 | 1.349 | 1.468 | 0.625 |
| Complexity: 3 SM | Two or no | 1.870 | 0.944 | 3.047* | 1.896 |
| Complexity: mseq | No mseq | 1.276 | 0.777 | 1.245 | 7.404*** |

3 SM, simultaneous movement types; mseq, movement sequence. *$p < 0.05$, ***$p < 0.001$.

our finding of handshape and movement as the most error-prone parameters.

## Handshape is difficult for everyone

As shown in **Table 3** in Section "Parameter accuracy," the accuracy of handshape is second lowest after movement, and handshape is more prone to errors as indicated by the fact that most feature-level errors were distributed in the handshape parameter. This pattern is consistent with diary studies of children acquiring ASL as a first language, in which handshape was controlled later than location and movement (McIntire, 1977; Boyes Braem, 1981; Siedlecki and Bonvillian, 1993). Studies of the development of ASL (Marentette and Mayberry, 2000; Cheek et al., 2001) and other sign languages (Clibbens and Harris, 1993; Takkinen, 2008; Lutzenberger, 2022) converge on the finding that handshape is produced with the most errors or modifications. Other pseudosign studies with signing children similarly report higher frequency of errors for handshape than for other parameters (Marshall et al., 2006; Mann et al., 2010; Cristini and Bogliotti, 2015).

There are several factors that potentially contribute to the disproportionately high error rate for handshape. One is the relatively large inventories of contrastive handshapes employed by sign languages, compared to smaller inventories of contrastive movements and locations (Meier et al., 2008; Orfanidou et al., 2009). With a greater number of distinct handshapes comes an increased level of detail that signers must attend to in order to distinguish between similar handshapes. Accordingly, the phonological representation for handshape is the most structurally complex, decomposable into smaller units of finger selection, joint position, and thumb position (Mandel, 1981; Brentari, 1998; van der Kooij, 2002; Sandler and Lillo-Martin, 2006), which correspond to the three properties of handshape we examined in this study. Accurate production of these handshape properties requires fine motor control of small, distal articulators (the fingers), demanding levels of coordination that often exceeds that of developing signers, whether young children (Conlin et al., 2000; Meier, 2005) or adult learners (Hohenberger et al., 2002; Emmorey et al., 2009; Ortega and Morgan, 2015; Mertz et al., 2022).

Within handshapes, our results also showed that those with higher complexity are reproduced with lower accuracy by ASL-signing children (age range: 4;0–8;10). This negative effect of handshape complexity has also been reported for pseudosigns reproduced by hearing adult native signers (referred to as codas, or children of deaf adults) of the Sign Language of the Netherlands/NGT (Klomp, 2015). In both cases, signers' poorer performance on pseudosigns with phonologically complex handshapes is consistent with longitudinal studies that report later acquisition of more complex handshapes in signing children's phonological development (Cheek et al., 2001; Karnopp, 2002; Morgan et al., 2007; Wong, 2008; Pan and Tang, 2017).

### Movement is difficult for everyone

As summarized in Section "Development of sign phonology," young signers display a variety of movement errors in their spontaneous production, many of which have been attributed to children's incomplete motor development. However, this explanation may be too simplistic, given that many of these same movement error patterns are also observed among adult sign language learners. Noting frequent proximalization errors in the ASL of hearing adults learning a sign language as a second language (referred to as M2L2 or second modality second language learners) and to a lesser extent, even in deaf adult signers, Mirus et al. (2001) suggest that this type of error is a modality-specific pattern that arises when learners of any age are faced with the "new and complex motor skill" (Mirus et al., 2001, p. 14) of coordinating the hands and arms in ways prescribed by an L2 sign language. Similarly, Hilger et al. (2015) report highly variable spatiotemporal patterns in adult M2L2 signing that may require years of exposure and practice to stabilize.

Problems in perception and processing also contribute to movement errors for both children and adults. The simple fact that sign languages employ two types of movement, internal and path movement, that often occur simultaneously is in itself a source of difficulty for learner perception or processing (this point is discussed further in Section "Modality effects on complexity"). Rosen (2004) argues that errors in which adult ASL learners correctly produce the path movement but not the simultaneous internal movement (e.g., producing the ASL sign for INFORMATION with the correct forward path movement, but with simultaneous closing of the hands from the  handshape to the  handshape rather than opening) reflect a perceptual error, and that these adult students possess the dexterity to produce the target form, but simply misremember the correct sequence of handshapes constituting the internal movement.

Other researchers have identified movement patterns that are particularly vulnerable to errors. Ebling et al. (2021) report especially high error rates for two movement patterns in their adult M2L2 learners' reproduction of isolated Swiss German Sign Language (DSGS) signs. The first involves horizontal circular movements produced in the wrong direction, which can be considered a type of "mirror" error (Rosen, 2004). Such errors are common among M2L2 signers and are attributed to the signer failing to first rotate the sign to their own perspective; indeed, Quandt et al. (2021) recently documented poorer mental rotation ability for beginning signers compared to fluent signers. The second "specially marked movement" reported for DSGS are those involving a sequence of an outward path followed by a downward path. Ebling et al. (2021) note that this sort of movement sequence is relatively rare in DSGS, and viewed from straight on, is apparently misperceived (and subsequently misproduced) by inexperienced signers as a single downward arc movement. This analysis is consistent with reports from Bochner et al. (2011) that adult hearing M2L2 learners' ability to discriminate movement contrasts in ASL is weaker than for other parameters, a finding replicated by Schlehofer and Tyler (2016) for other M2L2 learners of ASL. Similarly, Williams et al. (2016) report that adult learners misperceive sign movement more often than other parameters when viewing signed sentences.

Interestingly, although the movement parameter is most often misperceived (and thus misproduced) by learners, it is highly salient for experienced signers (Hildebrandt and Corina, 2002; Orfanidou et al., 2009). Examining M2L2 signers' non-target reproductions of DSGS signs that were rated as severe errors by experienced deaf judges, Ebling et al. (2021) report that non-target movements account for the majority of these errors (61%), far outstripping the second most salient parameter, handshape (20%). In other words, not only is movement the most commonly misperceived and misproduced parameter, deviations in this domain also contribute the most to viewers' perception of inaccurate or incorrect signing, suggesting that movement warrants additional attention in sign language pedagogy.

## Group differences

As indicated in **Table 4**, the deaf group and the DDCI group achieved higher accuracy scores than the koda group. It is noteworthy that performance on the pseudosign repetition task is positively associated with age (Marshall et al., 2006; Mann et al., 2010). As noted earlier, the children in the deaf group were older than those in the other groups, which could have given them an advantage on this task. Adjusted for age, the deaf group still outperformed the koda group, although no significant difference was found between the DDCI group and the other two groups. However, these results should be considered with caution since the sample size for these groups is small. Very little literature has compared deaf children, koda children, and DDCI children in any aspect of sign language development (but see Cruz et al., 2014; Reynolds, 2016; Kozak, 2018). In addition, there is a similar result comparing deaf and coda adults reported in Klomp (2018); she found that deaf adults were more accurate than codas in a NGT pseudosign repetition task.

We do not intend to make a claim here regarding group differences due to our small sample sizes and potential variations among the individuals' ASL and English input, even though they were all exposed to ASL from birth. Kodas are heritage signers (Chen Pichler et al., 2018; Reynolds, 2018) and as observed in other studies of heritage language learners, it is reasonable to infer that hearing bimodal bilinguals may follow distinct developmental patterns for some aspects of their grammar compared to deaf native signers. We also note that considerable deviations in thumb position were identified in the koda group as compared to the deaf and DDCI children (Kozak et al., 2022), although such deviations were perceived as lying somewhere between acceptable variation and real errors, as evaluated by the deaf researchers we consulted. Thumb position deviations occurred often when the target form involves a  handshape but the participants, particularly children in the koda group, produced these items with their thumb extended. This  handshape is arguably a permissible variation in ASL real signs (Battison et al., 1975; Lucas, 2001) and is frequently attested in connected ASL production (Cheek et al., 2001) as well as in other sign languages (e.g., Ormel et al., 2017). This kind of more frequent occurrences of thumb deviations among kodas might be affected by age since the average age of koda group is younger than the deaf group. The younger-aged children may be less sensitive to the formality of the tasks and more easily bored by the pseudosign task, giving rise to more informal use of the thumb. The older-aged children, in contrast, may have been more successful at staying focused and inhibiting acceptable variations, resulting in more accurate psuedosign reproduction. We leave these postulations to be examined in future research with larger samples.

## Modality effects on complexity

When considering how complexity of pseudowords (signed or spoken) relates to accuracy in reproduction, it is important to consider potential effects of modality on phonological complexity. Since pseudoword tasks require participants to perceive and remember novel stimuli that are not part of their mental lexicon, cognitive skills in perception, memory, and production are all relevant.

Let us consider the working memory factor, which is heavily taxed in pseudoword tasks. For children acquiring spoken languages, serial working memory develops throughout childhood, permitting the rote recall of increasingly longer sequences, including non-words composed of longer sequences of syllables (Gathercole and Baddeley, 1989; Gathercole et al., 1994). Adult deaf signers typically score lower than hearing speakers in tasks that require temporal sequencing of linguistic chunks (e.g., Hall and Bavelier, 2011). On the other hand, some studies report superior spatial coding abilities in deaf signers (e.g., Wilson and Emmorey, 2003; see Giezen, 2021 for an overview). ASL (and other sign languages) often packages information into simultaneously produced multimorphemic monosyllabic forms, rather than making extensive use of temporal sequencing as do spoken languages. It is hypothesized that this difference is related to the exact components of the working memory system that are constrained by the sensory modalities, as summarized in these references (Wilson et al., 1997; Emmorey et al., 2017; Brentari, 2019).

This difference in working memory preferences for spoken languages (sequential units) versus signed languages (simultaneous units) leads us to consider predicted differences between observed performance on spoken and signed pseudoword repetition tasks. For signers, longer sequences of units belonging to a single pseudosign could cause greater memory demands, especially in comparison to unit sequences of the same length in spoken languages. For speakers, length differences should be observed but only for more complex sequences. On the other hand, signing children may well be able to handle simultaneous complexity of various sorts, with complexity effects seen only beyond a certain threshold.

The results of our study are consistent with these predicted differences. Remarkably, neither the presence of two hands nor the presence of two simultaneous movement types led to reduced accuracy. Only when three simultaneous movements were presented was accuracy affected. This indicates that greater simultaneous sign complexity is within the processing capacity of our child participants. On the other hand, signed stimuli that exhibited sequential complexity on a par with disyllabic spoken words were reproduced with reduced accuracy. This is in contrast to spoken pseudoword tasks, in which children generally begin to show a breakdown in accuracy only once the word length reaches three or more syllables (Thal et al., 2005; Gathercole, 2006; Pham et al., 2018, a.o). In the following subsections we discuss each of these results in turn.

### Number of hands

On the purely motoric level, the use of two hands can be considered more complex than the use of one hand, as discussed in Section "Development of sign phonology" for deaf L1 sign learners (Meier et al., 2008) and hearing L2 sign learners (Ortega and Morgan, 2015). Learning to coordinate the handshapes and movement of the two hands, as well as the timing when each is available for production, requires time.

On the linguistic level, two-handed signs are not simply equivalent to two one-handed signs. In fact, the non-dominant hand (sometimes called the "weak" hand or H2) is very limited in what it can do within two-handed lexical items. Battison (1978) classified signs depending on number of hands and suggested constraints on the non-dominant hand, as summarized in Section "Sign language phonology" above. Battison's proposed symmetry and dominance conditions severely restrict the ways that the non-dominant hand is used. Other phonological models since then (Sandler, 1993; van der Hulst, 1996; Brentari, 1998; van der Kooij, 2002) have also emphasized the dependent status of the non-dominant hand. In addition, we did not find a difference in the overall accuracy of the two subtypes of two-handed items, namely symmetrical and asymmetrical signs. This suggests that regardless of how the non-dominant hand is restricted in a two-handed item (i.e., whether being subject to the symmetry condition or dominance condition), the presence of two hands does not impose difficulties on our child participants in this study.

These observations, together with our conception of simultaneous vs. sequential complexity, provide a reasonable explanation for the lack of an accuracy effect for pseudosign stimuli requiring the use of two hands vs. one hand.

## Simultaneous movement combinations

As described in Section "Materials" above, the stimuli in our study were classified according to the number of simultaneous movement types involved: one (either path or handshape/orientation change), two, or three simultaneous movement types. Our results showed a significant effect on accuracy for signs with three movement types compared to those with one or two: specifically, overall accuracy is significantly lower for the signs with three co-occurring movement types. When faced with three simultaneous movement types, the participants in our study tended to eliminate the orientation change, maintaining path movement and handshape change.

This response pattern may be related to a proposed phonotactic constraint within an ASL syllable whereby either handshape or orientation may change, but not both (Wilbur, 1993; Uyechi, 1995; Brentari, 1998; Sandler and Lillo-Martin, 2006)[10]. Studies in spoken languages report that pseudowords are more likely to be reproduced correctly if their structure is consistent with real words (Gathercole et al., 1991; Chiat, 2006), and pseudosigns with three simultaneous movement types violate this phonotactic constraint in ASL. Along a similar vein, Orfanidou et al. (2010) observe that deaf signers are quicker to identify real BSL signs embedded between pseudosigns if the pseudosigns are wordlike, i.e., if they resemble real BSL signs. It is very likely that children in our study perceived items with three simultaneous movement types as less wordlike than other forms with fewer movement combinations, negatively impacting their accuracy.

We conclude that the complexity associated with two simultaneous movement types is within the processing capacity of our participants. This also reflects reports that signs with one or two movement types far outnumber signs with three simultaneous movement types (Brentari, 1998 for ASL; Jantunen and Takkinen, 2010 for Finnish Sign Language). At first glance, our finding appears to contrast with the longitudinal results of Morgan et al. (2007) summarized in Section "Development of sign phonology," as well as a BSL pseudosign study conducted by Mann et al. (2010). The longitudinal study reported high error rates for real BSL signs with two simultaneous movement types, but the child in that study was much younger (19–24 months) than the children in the current study, making it likely that she was at a much earlier stage of motor and phonological development. The children studied by Mann et al. (2010) ranged from 3 to 11 years old and were observed to frequently simplify signs with two simultaneous movements [i.e., a simultaneous path movement and handshape change, referred to as "movement clusters"' by Mann et al. (2010)] through deletion of one of the movements. However, this error pattern occurred mostly in pseudosigns that also contained a complex handshape, reflecting an effect of combined handshape and movement complexity rather than of the movement cluster itself. As reported in Section "Multivariate analysis," we did not find a significant effect of handshape complexity on the performance in movement parameter, simultaneous movement types, although a significant effect was found on performance in movement sequence. Since Mann et al. (2010) did not test pseudosigns with more than two simultaneous movement types, the two studies are not directly comparable on this point.

## Sequential movement combinations

The results of our pseudosign repetition task show that disyllabic forms, i.e., those with a movement sequence, were produced less accurately than monosyllabic forms, i.e., those without a movement sequence. This implies that processing capacity for signs at the sequential level is highly limited, a manifestation of modality effects related to the dominance of simultaneous structuring in visual languages, as discussed earlier.

Pseudoword repetition tasks in spoken languages have generally found effects for length of the stimulus (in syllables). While such tasks are frequently used with school-age children and are often employed for diagnosing developmental language disorder or delays (e.g., Dollaghan and Campbell, 1998), they have also been used with children as young as 2–4 years of age (Roy and Chiat, 2004). The length effects show that typically-developing English-speaking children (age range: 4;0–8;11) usually reproduce one- and two-syllable words more accurately than longer words (Dollaghan and Campbell, 1998; Weismer et al., 2000; Thal et al., 2005). This can be taken as an indication that disyllabic words are not particularly demanding, but longer sequences do require greater phonological working memory for spoken words. Although not all pseudosign studies include monosyllabic stimuli, it can be concluded that children around the same age as those in our study are highly successful with at least disyllabic words. In spoken stimuli with more than two syllables, a length effect is generally found, such that the greater the number of syllables, the more errors there are in reproduction. These results indicate that two-syllable spoken pseudowords have a different phonological complexity status than two-syllable pseudosigns.

10 One reviewer pointed out that the wrist is rarely contrastive, and wrist movement is most often an enhancing effect of hand opening/closing and therefore more phonetic than phonological in ASL real signs (Brentari, 2019). The authors carefully examined the stimuli and concluded that these enhanced orientation changes as a secondary effect of hand-internal movement were not found in the pseudosign stimuli that were tested in this study. The orientation change in the stimuli design is not a phonetic effect, but contrastive.

The preference for monosyllables in pseudosigns reflects the common pattern of real signs consisting of a single syllable. Disyllabic signs exist, but they are rare, a distribution pattern that could be considered as reflecting a strong preference for signs to have at least one movement, but not more than one movement sequence in the temporal dimension (Coulter, 1982; Sandler, 1989; Wilbur, 1993; Brentari, 1998; van der Hulst and van der Kooij, 2021). Furthermore, when multisyllabic signs are found (e.g., in sign compounds), they often undergo phonological processes that reduce them toward the shape of a monosyllable (Liddell and Johnson, 1986; Brentari, 1998). Those findings are consistent with the results from our study, which indicate that children are able to apply such processes to reduce complexity, rendering pseudosigns more like the canonical form of real signs. The fact that sequential pseudosigns showed a lower reproduction accuracy tells us that again, wordlikeness is at play, since items with a movement sequence do not resemble the canonical form of real signs.

## Limitations and future directions

The results of this study indicate that complexity affects phonological development for signing children, but that they are not equally sensitive to all types of complexity. Specifically, signs with sequential movement complexity negatively impacted accuracy, while those with some simultaneous movement complexity did not. This finding raises intriguing questions about modality and language development to be addressed in future research. For instance, closer examination of the effects of simultaneous complexity on spoken language development would clarify whether the differential effects of simultaneous vs. sequential complexity we observed for signers also occurs for spoken language learners, e.g., perhaps in the context of complex tone patterns (Pham et al., 2018) or accent patterns (Sundström et al., 2014) accompanying speech. Additionally, expanding our investigation to other populations of sign language learners is important for understanding the effect of additional factors such as age of exposure (AoA) and quality of early sign language input. Our study examined only participants who had the benefit of exposure to a natural sign language from birth, a privilege limited to only a very small percentage of deaf or hard of hearing (DHH) children worldwide [fewer than 3.9% in the United States, according to Mitchell and Karchmer (2004)]. A much larger percentage of DHH children experience limited or delayed first language acquisition, a factor that has been shown to impact patterns in phonological accuracy on real signs among deaf adult signers (Nielson and Mayberry, 2021). Other pseudosign repetition studies have investigated signing children from Deaf families compared to those from hearing families (Quadros et al., 2012; Cristini and Bogliotti, 2015) and found that those from Deaf families achieved higher scores on the task compared to those from hearing families.

Additionally, our task was limited in scope, including only 22 participants across three groups whose ages were not balanced. Mann et al. (2010) investigated pseudosign repetition among BSL signers across a wider age range than ours and found a correlation between age and accuracy. Expanding our current cohort in both number and ages will be necessary for a more comprehensive investigation of the nature of group effects throughout childhood. Adult native signing controls should also be introduced for comparison purposes to the experimental groups.

Finally, while other studies involving these same participants have investigated pseudosign reproduction accuracy and its correlation to other phonological abilities (Cruz et al., 2014; Kozak, 2018), further investigation with wider scope should be conducted to see how these skills overall interact with participants' phonological recall ability.

## Conclusion

In this study of pseudosign repetition task with L1 ASL-signing children, we found that children's overall accuracy increased by age, and the accuracy on individual sign parameters was relatively high for location and orientation, but lower for handshape and movement. We reported that items with no movement sequence are significantly associated with better performance. Also, children achieved significantly better performance on items with a single movement or two simultaneous movement types than those with three simultaneous movement types. Finally, accuracy scores between two-handed and one-handed items were not significantly different. We conclude that simultaneous versus sequential phonological structure differ as sources of complexity in signed and spoken (non-)words. This modality effect in turn influences children's processing patterns in the signed modality. The ability of signing children to process multiple simultaneous components, as revealed in our study, informs their phonological development in the visual-gestural modality. In light of these findings, we advance the employment of phonological complexity in the assessment of working memory and phonological skills in psycholinguistic studies of both spoken and signed languages.

## Data availability statement

The datasets presented in this study can be found at: https://osf.io/93cne/?view_only=0a7e72095d824a7db3b08453e6dc3e34.

## Ethics statement

The studies involving human participants were reviewed and approved by the Institutional Review Boards of the University of Connecticut and Gallaudet University. Written informed consent to participate in this study was provided by the participants or their legal guardian/next of kin. Written informed consent was obtained from the individual(s), and minor(s)' legal guardian/next of kin, for the publication of any potentially identifiable images or data included in this article.

## Author contributions

SG conducted the primary analyses and wrote a first draft of multiple sections. LK conducted additional analyses. DL-M and DC supervised the project and acquired the funding. All authors contributed to conception, drafting and revising the manuscript, and approved the submitted version.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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## Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2022.921047/full#supplementary-material

## References

Bates, D., Mächler, M., Bolker, B., and Walker, S. (2015). Fitting linear mixed-effects models using lme4. *J. Stat. Softw.* 67, 1–48. doi: 10.18637/jss.v067.i01

Battison, R. (1978). *Lexical Borrowing in American Sign Language.* Silver Spring, MD: Linstok Press.

Battison, R., Markowicz, H., and Woodward, J. (1975). "A good rule of thumb: variable phonology in american sign language," in *Analyzing Variation in Language: Papers from the Second Colloquium on New Ways of Analyzing Variation*, eds W. F. Ralph and W. Roger (Washington D.C: Georgetown University Press), 291–302.

Bochner, J. H., Christie, K., Hauser, P. C., and Searls, J. M. (2011). When is a difference really different? Learners' discrimination of linguistic contrasts in American Sign Language. *Language Learn.* 61, 1302–1327. doi: 10.1111/j.1467-9922.2011.00671.x

Bonvillian, J. D., and Siedlecki, T. (1996). Young children's acquisition of the location aspect of american sign language signs: parental report findings. *J Commun. Disord.* 29, 13–35. doi: 10.1016/0021-9924(94)00015-8

Boyes Braem, P. (1981). *Significant Features of the Handshape in American Sign Language.* [doctoral dissertation]. Berkeley, CA: University of California.

Boyes Braem, P. (1990). "Acquisition of the handshape in American Sign Language: a preliminary analysis," in *From Gesture to Language in Hearing and Deaf Children Springer Series in Language and Communication*, eds V. Volterra and C. J. Erting (Berlin: Springer), 107–127. doi: 10.1007/978-3-642-74859-2_10

Brentari, D. (1998). *A Prosodic Model of Sign Language Phonology*. Cambridge, MA: MIT Press. doi: 10.7551/mitpress/5644.001.0001

Brentari, D. (2019). *Sign Language Phonology*. Cambridge, CA: Cambridge University Press. doi: 10.1017/9781316286401

Brentari, D., Coppola, M., Cho, P. W., and Senghas, A. (2017). Handshape complexity as a precursor to phonology: Variation, emergence, and acquisition. *Language Acquisit.* 24, 283–306. doi: 10.1080/10489223.2016.1187614

Brentari, D., Ergin, R., Senghas, A., Cho, P. W., Owens, E., and Coppola, M. (2021). Community interactions and phonemic inventories in emerging sign languages. *Phonology* 38, 571–609. doi: 10.1017/S0952675721000336

Caselli, N. K., and Pyers, J. E. (2017). The road to language learning is not entirely iconic: iconicity, neighborhood density, and frequency facilitate acquisition of sign language. *Psychol. Sci.* 28, 979–987. doi: 10.1177/0956797617700498

Cheek, A., Cormier, K., Repp, A., and Meier, R. P. (2001). Prelinguistic gesture predicts mastery and error in the production of early signs. *Language* 77, 292–323. doi: 10.1353/lan.2001.0072

Chen Pichler, D. (2011). "Sources of handshape error in first-time signers of ASL," in *Deaf Around the World: The Impact of Language*, eds G. Mathur and D. Jo Napoli (New York, NY: Oxford University Press), 96–121. doi: 10.1093/acprof:oso/9780199732548.003.0005

Chen Pichler, D., Kuntze, M., Lillo-Martin, D., Quadros, R. M., and Stumpf, M. R. (2018). *Sign Language Acquisition by Deaf and Hearing Children: A Bilingual Introduction*. Washington, DC: Gallaudet University Press.

Chiat, S. (2006). The developmental trajectory of nonword repetition. *Appl. Psycholinguist.* 27, 552–556. doi: 10.1017/S014271640623039X

Clibbens, J., and Harris, M. (1993). "Phonological processes and sign language development," in *Critical Influences on Child Language Acquisition and Development*, eds D. J. Messer and G. J. Turner (London: Palgrave Macmillan), 197–208. doi: 10.1007/978-1-349-22608-5_10

Conlin, K. E., Mirus, G. R., Mauk, C. E., and Meier, R. (2000). "The acquisition of first signs: Place, handshape, and movement," in *Language Acquisition by Eye*, eds C. Chamberlain, J. P. Morford, and R. I. Mayberry (Mahwah, NJ: Lawrence Erlbaum and Associates), 51–69. doi: 10.4324/9781410601766-16

Corina, D., and Sandler, W. (1993). On the nature of phonological structure in sign language. *Phonology* 10, 165–207. doi: 10.1017/S0952675700000038

Coulter, G. (1982). On the nature of ASL as a monosyllabic language. *Paper presented at the Annual Meeting of the Linguistic Society of America*, San Diego, CA.

Cristini, M., and Bogliotti, C. (2015). The phonology of French Sign Language (LSF): Non-sign repetition and discrimination tests. *Paper Presented at the 2nd International Conference on Sign Language Acquisition (ICSLA 2)*, Amsterdam.

Cruz, C. R., Kozak, L. V., Pizzio, A. L., Quadros, R. M., and Chen Pichler, D. (2014). "Phonological memory and phonological acquisition in bimodal bilingual children," in *Proceedings of the 38th Annual Boston University Conference on Language Development*, eds W. Orman and M. J. Valleau (Somerville, MA: Cascadilla Press), 103–115.

Dollaghan, C., and Campbell, T. F. (1998). Nonword repetition and child language impairment. *J. Speech Lang. Hear. Res.* 41, 1136–1146. doi: 10.1044/jslhr.4105.1136

dos Santos, C., and Ferré, S. (2018). A nonword repetition task to assess bilingual children's phonology. *Lang. Acquisit.* 25, 58–71. doi: 10.1080/10489223.2016.1243692

Ebert, K. D., Kalanek, J., Cordero, K. N., and Kohnert, K. (2008). Spanish nonword repetition: Stimuli development and preliminary results. *Commun. Disord. Q.* 29, 67–74. doi: 10.1177/1525740108314861

Ebling, S., Tissi, K., Sidler-Miserez, S., Schlumpf, C., and Boyes Braem, P. (2021). Single-parameter and parameter combination errors in L2 productions of Swiss German Sign Language. *Sign Lang. Linguist.* 24, 143–181. doi: 10.1075/sll.19002.ebl

Eccarius, P., and Brentari, D. (2006). Symmetry and dominance: a cross-linguistic study of signs and classifier constructions. *Lingua* 117, 1169–1201. doi: 10.1016/j.lingua.2005.04.006

Eccarius, P., and Brentari, D. (2008). Handshape coding made easier: a theoretically based notation for phonological transcription. *Sign Lang. Linguist.* 11, 69–101. doi: 10.1075/sll.11.1.11ecc

Emmorey, K., Bosworth, R., and Kraljic, T. (2009). Visual feedback and self-monitoring of sign language. *J Memory Lang.* 61, 398–411. doi: 10.1016/j.jml.2009.06.001

Emmorey, K., Giezen, M. R., Petrich, J. A. F., Spurgeon, E., and O'Grady Farnady, L. (2017). The relation between working memory and language comprehension in signers and speakers. *Acta Psychol.* 177, 69–77. doi: 10.1016/j.actpsy.2017.04.014

Fenlon, J., Cormier, K., and Schembri, A. (2015). Building BSL signbank: the lemma dilemma revisited. *Int. J. Lexicography* 28, 169–206. doi: 10.1093/ijl/ecv008

Friedman, L. A. (1975). Phonological processes in the American Sign Language. *Ann. Meeting Berkeley Linguist Soc.* 1, 147–159. doi: 10.3765/bls.v1i0.2341

Gathercole, S. E. (2006). Nonword repetition and word learning: the nature of the relationship. *Appl. Psycholinguist.* 27, 513–543. doi: 10.1017/S0142716406060383

Gathercole, S. E., and Baddeley, A. D. (1989). Evaluation of the role of phonological STM in the development of vocabulary in children: a longitudinal study. *J Memory Lang.* 28, 200–213. doi: 10.1016/0749-596X(89)90044-2

Gathercole, S. E., Willis, C., Emslie, H., and Baddeley, A. D. (1991). The influences of number of syllables and wordlikeness on children's repetition of nonwords. *Applied Psycholinguistics* 12, 349–367. doi: 10.1017/S0142716400009267

Gathercole, S. E., Willis, C. S., Baddeley, A. D., and Emslie, H. (1994). The children's test of nonword repetition: a test of phonological working memory. *Memory* 2, 103–127. doi: 10.1080/09658219408258940

Giezen, M. R. (2021). "Working memory in signers: experimental perspectives," in *The Routledge Handbook of Theoretical and Experimental Sign Language Research*, eds J. Quer, R. Pfau, and A. Herrmann (London: Routledge), 664–684. doi: 10.4324/9781315754499-29

Hall, M. L., and Bavelier, D. (2011). Short-term memory stages in sign vs. speech: the source of the serial span discrepancy. *Cognition* 120, 54–66. doi: 10.1016/j.cognition.2011.02.014

Henner, J., Geer, L. C., and Lillo-Martin, D. C. (2013). "Calculating frequency of occurrence of ASL handshapes," in *Proceedings of the LSA annual meeting extended abstracts*, Vol. 4, Boston, MA, 1–4. doi: 10.3765/exabs.v0i0.764

Hildebrandt, U., and Corina, D. (2002). Phonological similarity in American Sign Language. *Lang. Cogn. Proc.* 17, 593–612. doi: 10.1080/01690960143000371

Hilger, A. I., Loucks, T. M., Quinto-Pozos, D., and Dye, M. W. (2015). Second language acquisition across modalities: Production variability in adult L2 learners of American Sign Language. *Second Lang. Res.* 31, 375–388. doi: 10.1177/0267658315570648

Hochgesang, J., Crasborn, O. A., and Lillo-Martin, D. C. (2021). *ASL Signbank. New Haven, CT: Haskins Lab, Yale University*. Available online at: https://aslsignbank.haskins.yale.edu/ (accessed June 10, 2022).

Hohenberger, A., Happ, D., and Leuninger, H. (2002). "Modality-dependent aspects of sign language production: evidence from slips of the hands and their repairs in german sign language," in *Modality and Structure in Signed and Spoken Languages*, eds R. P. Meier, K. Cormier, and D. Quinto-Pozos (Cambridge, CA: Cambridge University Press), 112–142. doi: 10.1017/CBO9780511486777.006

Holzrichter, A. S., and Meier, R. P. (2000). "Child-directed signing in American Sign Language," in *Language Acquisition by Eye*, eds C. Chamberlain, J. P. Morford, and R. I. Mayberry (Mahwah, NJ: Lawrence Erlbaum Associates Publishers), 25–40.

Jantunen, T. (2015). How long is the sign? *Linguistics* 53, 93–124. doi: 10.1515/ling-2014-0032

Jantunen, T., and Takkinen, R. (2010). "Syllable structure in sign language phonology," in *Sign Languages*, ed. D. Brentari (Cambridge, CA: Cambridge University Press), 312–331. doi: 10.1017/CBO9780511712203.015

Jissink, T. (2005). *How do you drive a car? Phonological acquisition order for hearing adult learners of Sign Language of the Netherlands.* [master's thesis]. Amsterdam: University of Amsterdam.

Kantor, R. (1980). The acquisition of classifiers in American Sign Language. *Sign Lang. Stud.* 1028, 193–208. doi: 10.1353/sls.1980.0000

Karnopp, L. (2002). "Phonology acquisition in Brazilian Sign Language," in *Directions in Sign Language Acquisition*, eds G. Morgan and B. Woll (Amsterdam: John Benjamins), 29–53. doi: 10.1075/tilar.2.05kar

Karnopp, L. B. (2008). "Sign phonology acquisition in Brazilian Sign Language," in *Sign Languages: Spinning and Unraveling the Past, Present and Future*, ed. R. M. deQuadros (RJ. Brazil: Editora Arara Azul. Petrópolis), 204–218.

Klima, E. S., and Bellugi, U. (1979). *The Signs of Language*. Cambridge, MA: Harvard University Press.

Klomp, U. (2015). *Making Sense of a Nonsense Sign Repetition Task*. [master's thesis]. Amsterdam: University of Amsterdam.

Klomp, U. (2018). "Starting to make sense: Further developing a nonsense sign repetition task," in *FEAST. Formal and Experimental Advances in Sign language Theory*, 2, eds V. Kimmelman and E. Koulidobrova 103–115. doi: 10.31009/FEAST.i2.09

Koulidobrova, E., and Ivanova, N. (2020). "Acquisition of phonology in child Icelandic sign language: Unique findings," in *Proceedings of the Linguistic Society of America*, Vol. 5, ed. P. Farrell (New Orleans, LA: LSA), 164–179. doi: 10.3765/plsa.v5i1.4697

Kozak, L. V. (2018). *Phonological processing by bimodal bilingual children. [doctoral dissertation]*. Washington, D.C: Gallaudet University.

Kozak, L. V., Gu, S., Chen Pichler, D., and Lillo-Martin, D. (2022). Phonological development in ASL signing children: comparing approaches to scoring a pseudosign repetition task. *Paper Presented at the 4th International Conference on Sign Language Acquisition (ICSLA 4)*, (Boston, MA: Boston University).

Lee, H. J., Kim, Y. T., and Yim, D. (2013). Non-word repetition performance in Korean-English bilingual children. *Int. J. Speech-Lang. Pathol.* 15, 375–382. doi: 10.3109/17549507.2012.752866

Liddell, S. K., and Johnson, R. E. (1986). American sign language compound formation processes, lexicalization, and phonological remnants. *Nat. Lang. Linguist. Theory* 4, 445–513. doi: 10.1007/BF00134470

Lucas, C. (2001). *The Sociolinguistics of Sign Languages*. Cambridge, CA: Cambridge University Press. doi: 10.1017/CBO9780511612824

Lutzenberger, H. (2022). *Kata Kolok phonology: Variation and acquisition.* [doctoral dissertation]. Nijmegen: Radboud University.

Mandel, M. (1981). *Phonotactics and Morphophonology in American Sign Language.* [doctoral dissertation]. Berkeley, CA: University of California.

Mann, W., Marshall, C. R., Mason, K., and Morgan, G. (2010). The acquisition of sign language: The impact of phonetic complexity on phonology. *Lang. Learn. Dev.* 6, 60–86. doi: 10.1080/15475440903245951

Marentette, P. F. (1995). *It's in her hands: A case study of the emergence of phonology in American Sign Language.* [doctoral dissertation]. Montreal: McGill University.

Marentette, P. F., and Mayberry, R. I. (2000). "Principles for an emerging phonological system: a case study of acquisition of ASL," in *Language Acquisition by Eye*, eds C. Chamberlain, J. P. Morford, and R. Mayberry (Mahwah, NJ: Lawrence Erlbaum and Associates), 71–90.

Marshall, C. R., Denmark, T., and Morgan, G. (2006). Investigating the underlying causes of SLI: A non-sign repetition test in British Sign Language. *Adv. Speech Lang. Pathol.* 8, 347–355. doi: 10.1080/14417040600970630

McBurney, S. (2002). "Pronominal reference in signed and spoken language: Are grammatical categories modality-dependent?," in *Modality and Structure in Signed and Spoken Languages*, eds R. P. Meier, K. Cormier, and D. Quinto-Pozos (Cambridge, CA: Cambridge University Press), 329–369. doi: 10.1017/CBO9780511486777.017

McIntire, M. L. (1977). The acquisition of American Sign Language hand configurations. *Sign Lang. Stud.* 1016, 247–266. doi: 10.1353/sls.1977.0019

Meier, R. P. (2005). "The form of early signs: Explaining signing children's articulatory development," in *Advances in the Sign-Language Development of Deaf Children*, eds B. Schick, M. Marschark, and P. E. Spencer (Oxford: Oxford University Press), 202–230. doi: 10.1093/acprof:oso/9780195180947.003.0009

Meier, R. P., Mauk, C. E., Cheek, A., and Moreland, C. J. (2008). The form of children's early signs: Iconic or motoric determinants? *Lang. Learn. Dev.* 4, 63–98. doi: 10.1080/15475440701377618

Mertz, J., Annucci, C., Aristodemo, V., Giustolisi, B., Gras, D., Turco, G., et al. (2022). Measuring sign complexity: comparing a model-driven and an error-driven approach. *Lab. Phonol.* 24, doi: 10.16995/labphon.6439

Mirus, G. R., Rathmann, C., and Meier, R. P. (2001). "Proximalization and distalization of sign movement in adult learners," in *Sign Languages: Discoveries from International Research*, eds V. Dively, M. Metzger, S. Taub, and A. M. Baer (Washington, D.C: Gallaudet University Press), 103–119.

Mitchell, R. E., and Karchmer, M. A. (2004). Chasing the mythical ten percent: Parental hearing status of deaf and hard of hearing students in the United States. *Sign Lang. Stud.* 4, 138–163. doi: 10.1353/sls.2004.0005

Morgan, G., Barrett-Jones, S., and Stoneham, H. (2007). The first signs of language: phonological development in british sign language. *Appl. Psycholinguist.* 28, 3–22. doi: 10.1017/S0142716407070014

Morgan, H., Novogrodsky, R., and Sandler, W. (2019). Phonological complexity and frequency in the lexicon: A quantitative cross-linguistic study. *Paper Presented at the 13th Theoretical Issues in Sign Language Research (TISLR 13)*, Hamburg.

Nielson, S., and Mayberry, R. (2021). Late first language acquisition alters the organization of the phonological system of ASL. *Paper Presented at the 46th Annual Boston University Conference on Language Development (BUCLD 46)*, (Boston, MA: Boston University).

Orfanidou, E., Adam, R., McQueen, J. M., and Morgan, G. (2009). Making sense of nonsense in British Sign Language (BSL): The contribution of different phonological parameters to sign recognition. *Memory Cogn.* 37, 302–315. doi: 10.3758/MC.37.3.302

Orfanidou, E., Adam, R., Morgan, G., and McQueen, J. M. (2010). Recognition of signed and spoken language: different sensory inputs, the same segmentation procedure. *J. Memory Lang.* 62, 272–283. doi: 10.1016/j.jml.2009.12.001

Ormel, E., Crasborn, O., Kootstra, G., and Meijer, A. D. (2017). Coarticulation of handshape in Sign Language of the Netherlands: a corpus study. *Lab. Phonol.* 8:10. doi: 10.5334/labphon.45

Ortega, G., and Morgan, G. (2015). Phonological development in hearing learners of a sign language: The influence of phonological parameters, sign complexity, and iconicity. *Lang. Learn.* 65, 660–688. doi: 10.1111/lang.12123

Pan, Z., and Tang, G. (2017). Deaf children's acquisition of the phonetic features of handshape in Hong Kong Sign Language (HKSL). *Paper Presented at the 6th Formal and Experimental Approaches to Sign Theory (FEAST 6)*, (Reykjavik: University of Reykjavik).

Perlmutter, D. M. (1992). Sonority and syllable structure in American Sign Language. *Linguist. Inquiry* 23, 407–442.

Pham, G., Ebert, K. D., Dinh, K. T., and Dam, Q. (2018). Nonword repetition stimuli for Vietnamese-speaking children. *Behav. Res. Methods* 50, 1311–1326. doi: 10.3758/s13428-018-1049-0

Quadros, R. M., Chen Pichler, D., Lillo-Martin, D., Cruz, C. R., Kozak, L. V., Palmer, J. L., et al. (2015). "Methods in bimodal bilingualism research: Experimental studies," in *The Blackwell Guide to Research Methods in Sign Language Studies*, eds E. Orfanidou, B. Woll, and G. Morgan (Oxford: Blackwell), 250–280. doi: 10.1002/9781118346013.ch14

Quadros, R. M., Lillo-Martin, D., and Chen Pichler, D. (2012). "Bi-national bi-modal bi-lingual corpora of child language," in *Proceedings of the VIIth GSCP [Gruppo di Studi sulla Comunicazione Parlata] International Conference: Speech and Corpora*, eds H. Mello, M. Pettorino, and T. Raso (Firenze: Firenze University Press), 87–92.

Quadros, R. M., Lillo-Martin, D., and Chen Pichler, D. (2014). "Methodological considerations for the development and use of sign language acquisition corpora," in *Spoken Corpora and Linguistic Studies*, eds T. Raso and H. Mello (Amsterdam: John Benjamins), 84–102. doi: 10.1075/scl.61.03qua

Quandt, L. C., Kubicek, E., Willis, A., and Lamberton, J. (2021). Enhanced biological motion perception in deaf native signers. *Neuropsychologia* 161:107996. doi: 10.1016/j.neuropsychologia.2021.107996

R Core Team (2021). *R: A language and Environment for Statistical Computing*. Vienna: R Foundation for Statistical Computing.

Reynolds, W. (2016). *Early bimodal bilingual development of ASL narrative referent cohesion: Using a heritage language framework.* [doctoral dissertation]. Washington, D.C: Gallaudet University.

Reynolds, W. (2018). Young bimodal bilingual development of referent tracking in signed narratives: Further justification of heritage signer status. *Sign Lang. Stud.* 18, 328–354. doi: 10.1353/sls.2018.0006

Rosen, R. S. (2004). Beginning L2 production errors in ASL lexical phonology: A cognitive phonology model. *Sign Lang. Linguist.* 7, 31–61. doi: 10.1075/sll.7.1.04beg

Roy, P., and Chiat, S. (2004). A prosodically controlled word and nonword repetition task for 2- to 4-year-olds. *J Speech Lang. Hear. Res.* 47, 223–234. doi: 10.1044/1092-4388(2004/019)

Sandler, W. (1989). *Phonological Representation of the Sign: Linearity and Nonlinearity in American Sign Language*. Dordrecht: Foris. doi: 10.1515/9783110250473

Sandler, W. (1993). Hand in hand: The roles of the nondominant hand in sign language phonology. *Linguist. Rev.* 10, 337–390. doi: 10.1515/tlir.1993.10.4.337

Sandler, W. (2017). The challenge of sign language phonology. *Ann. Rev. Linguist.* 3, 43–63. doi: 10.1146/annurev-linguistics-011516-034122

Sandler, W., and Lillo-Martin, D. (2006). *Sign Language and Linguistic Universals*. Cambridge, CA: Cambridge University Press. doi: 10.1017/CBO9781139163910

Santos, F. H., Bueno, O. F. A., and Gathercole, S. E. (2006). Errors in nonword repetition: bridging short- and long-term memory. *Brazilian J. Med. Biol. Res.* 39, 371–385. doi: 10.1590/S0100-879X2006000300008

Schlehofer, D. A., and Tyler, I. J. (2016). Errors in second language learners' production of phonological contrasts in American Sign Language. *Int. J. Lang. Linguist.* 3, 30–38.

Siedlecki, T., and Bonvillian, J. D. (1993). Location, handshape & movement: Young children's acquisition of the formational aspects of American Sign Language. *Sign Lang. Stud.* 1078, 31–52. doi: 10.1353/sls.1993.0016

Siedlecki, T., and Bonvillian, J. D. (1997). Young children's acquisition of the handshape aspect of American Sign Language signs: parental report findings. *Appl. Psycholinguist.* 18, 17–39. doi: 10.1017/S0142716400009851

Stokoe, W. (1960). "Sign language structure: An outline of the visual communication systems of the American deaf," in *Studies in Linguistics: Occasional Papers 8*, (Silver Spring, MD: Linstok Press), 3–78.

Sundström, S., Samuelsson, C., and Lyxell, B. (2014). Repetition of words and non-words in typically developing children: the role of prosody. *First Lang.* 34, 428–449. doi: 10.1177/0142723714550213

Takkinen, R. (2008). "The acquisition of finnish sign language," in *Research in Logopedics*, eds A. Klippi and K. Launonen (Bristol: Multilingual Matters), 175–205. doi: 10.21832/9781847690593-011

Thal, D. J., Miller, S., Carlson, J., and Vega, M. M. (2005). Nonword repetition and language development in 4-year-old children with and without a history of early language delay. *J. Speech Lang. Hear. Res.* 48, 1481–1495. doi: 10.1044/1092-4388(2005/103)

Uyechi, L. N. (1995). *The Geometry of Visual Phonology.* [doctoral dissertation]. Stanford, CA: Standford University.

van der Hulst, H. (1993). Units in the analysis of signs. *Phonology* 10, 209–241. doi: 10.1017/S095267570000004X

van der Hulst, H. (1996). On the other hand. *Lingua* 98, 121–143. doi: 10.1016/0024-3841(95)00035-6

van der Hulst, H., and van der Kooij, E. (2021). "Sign language phonology: theoretical perspectives," in *The Routledge Handbook of Theoretical and Experimental Sign Language Research*, eds J. Quer, R. Pfau, and A. Herrmann (London: Routledge), 1–32. doi: 10.4324/9781315754499-1

van der Kooij, E. (2002). *Phonological Categories in Sign Language of the Netherlands: The Role of Phonetic Implementation and Iconicity.* [doctoral dissertation]. Leiden: Leiden University.

Vink, L. (2018). *Looking for complexity: an analysis of NGT nonsense signs in the Dependency Model.* [master's thesis]. Amsterdam: University of Amsterdam.

Weismer, S. E., Tomblin, J. B., Zhang, X., Buckwalter, P., Chynoweth, J. G., and Jones, M. (2000). Nonword repetition performance in school-age children with and without language impairment. *J. Speech Lang. Hear. Res.* 43, 865–878. doi: 10.1044/jslhr.4304.865

Wilbur, R. B. (1993). "Syllables and segments: Hold the movements and move the holds," in *Current Issues in ASL Phonology*, ed. G. Coulter (San Diego, CA: Academic Press), 135–168. doi: 10.1016/B978-0-12-193270-1.50012-1

Wilbur, R. B. (2011). "Sign syllables," in *The Blackwell Companion to Phonology*, eds M. van Oostendorp, C. J. Ewen, E. Hume, and K. Rice (Oxford: John Wiley & Sons, Ltd), 1–26. doi: 10.1002/9781444335262.wbctp0056

Williams, J. T., Darcy, I., and Newman, S. D. (2016). Modality-specific processing precedes amodal linguistic processing during L2 sign language acquisition: a longitudinal study. *Cortex* 75, 56–67. doi: 10.1016/j.cortex.2015.11.015

Willoughby, L., Linder, S., Ellis, K., and Fisher, J. (2015). Errors and feedback in the beginner Auslan classroom. *Sign Lang. Stud.* 15, 322–347. doi: 10.1353/sls.2015.0009

Wilson, M., Bettger, J., Niculae, I., and Klima, E. (1997). Modality of language shapes working memory: evidence from digit span and spatial span in ASL signers. *J. Deaf Stud. Deaf Educ.* 2, 150–160. doi: 10.1093/oxfordjournals.deafed.a014321

Wilson, M., and Emmorey, K. (2003). The effect of irrelevant visual input on working memory for sign language. *J. Deaf Stud. Deaf Educ.* 8, 97–103. doi: 10.1093/deafed/eng010

Wong, Y. (2008). *Acquisition of Handshape in Hong Kong sign language: A case study.* [master's thesis]. Hong Kong: Chinese University of Hong Kong.

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# Sign learning and its use in a co-enrollment kindergarten setting

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Experimental studies report positive effects of signing for language acquisition and communication in children with and without language development delays. However, little data are available on natural kindergarten settings. Therefore, our study used questionnaire data to investigate the sign learning in hearing children (aged 3;7–5;9 years) with and without language development delays in an inclusive kindergarten group with a co-enrolled deaf child (aged 3;8 years) and a deaf signing educator. We observed that the hearing children in this co-enrollment group learned more signs than the hearing children from groups with only hearing educators who learned signs in a training program. Hearing children's sign learning showed a tendency toward correlating positively with their level of spoken language development. However, the individual background for children with language development delays impacted this relationship. Additionally, we examined the modality use of all children in interactions with hearing and deaf educators and peers using questionnaire and video data. Despite acquiring signs, hearing children predominantly used spoken language with hearing educators and predominantly nonverbal communication strategies with the deaf educator and the deaf child. Children with language development delays used code-blending with hearing educators in a few cases. The deaf child used mainly sign language for interactions with the deaf educator and mainly nonverbal communication with hearing educators and peers. Overall, our results suggest that the presence of a deaf educator increases sign learning in hearing children. However, in interactions during free play, they barely used signs making it particularly challenging for the deaf child to participate. This reveals that, in addition to a deaf role model, more sign language competent peers and targeted approaches increasing the use of the visual modality are required.

KEYWORDS

**sign language, language learning, co-enrollment, kindergarten, language development delay, deaf**

## Introduction

Communication skills are key to participating in interactions (Guralnick et al., 1996, 2006; Odom et al., 2002). Interactions, in turn, are related to other areas of development, such as social–emotional skills, cognition and language (see DeLuzio and Girolametto, 2011). Deaf children and children with delayed spoken language abilities are at risk of being excluded from interactions (Odom et al., 2002; Preisler et al., 2002). For deaf children, communication in sign language offers the possibility to take part in verbal interactions (Marschark et al., 2006). Moreover, for hearing children with and without language development delays, studies reported that signs or gestures can increase communicative abilities (Bonvillian et al., 1981; DiCarlo et al., 2001). Consequently, the extent to which the visual modality is used by all group members in interactions is particularly crucial for the development of deaf children and children with spoken language development delays. Therefore, our study focuses not only on sign language learning but also on its use in a co-enrollment kindergarten setting with a deaf child and hearing children with and without language development delays.

### Sign learning in deaf and hearing preschool children

Deaf children of deaf parents acquire sign language from their parents as native languages and reach similar milestones at similar ages compared to hearing children acquiring spoken languages (Chen Pichler, 2012). This access to a perceptible language offers age-appropriate language, cognitive, and social–emotional development (Marschark et al., 2006). Besides studies reporting positive effects of signs or gestures on spoken language acquisition in children with various profiles, several studies investigated the extent to which signs are used to communicate by different target groups. These studies were based on the hypothesis that children could possibly bypass or compensate for certain abilities necessary for spoken language *via* the visuospatial modality (Bonvillian et al., 1981; Kay-Raining Bird et al., 2000). Already many decades ago, it was suggested that the motoric, visual, and kinesthetic skills in children with autism are more advanced compared to their auditory-verbal ones (O'Connor, 1971). Moreover, for children with Down syndrome, studies have shown that their visual memory is more developed compared to their auditory memory (Kay-Raining Bird and Chapman, 1994). In fact, studies found some children with autism to acquire signs faster than spoken words (for an overview, see Bonvillian et al., 1981; Nunes, 2008). Additionally, children with Down syndrome and typically developing children learned novel words better if the words were presented in parallel with signs than when words or signs were presented separately (Kay-Raining Bird et al., 2000). Producing intelligible spoken language often presents a motor challenge for children with Down syndrome while signing requires less precise fine motor skills (Kay-Raining Bird et al., 2000). Based on this observation, signing is offered to hearing babies and young children to provide another way of communication until fine motor skills are developed (Kay-Raining Bird et al., 2000). Therefore, signs are sometimes offered to children in kindergarten settings but only a few studies on sign learning in hearing children with and without disabilities are available.

A study by DiCarlo et al. (2001) assessed the spoken language development and sign learning in toddlers with and without disabilities (aged 1;3-3;0 years) of two inclusive classrooms in which signs had been implemented in hearing teacher-child interactions. They observed that some signs were learned while the development of spoken language was not inhibited. Wijkamp et al. (2010) investigated the sign learning of children with severe language development delays (aged 2;6–4;7 years) in a setting where Sign Supported Dutch was used by the hearing educational staff and therapists. They found some children to have learned single signs, especially when there was little auditory-vocal communication. A recent larger study by Schüler et al. (2021) investigated the sign learning of children with and without language development delays in inclusive kindergarten groups. The hearing educators in these groups participated in a training program familiarizing them with signs and their use. Six months after implementing the sign training sessions, Schüler et al. (2021) reported a significant increase in the children's sign vocabulary. However, language role modeling impacted children's sign acquisition significantly: in groups with hearing teachers using many signs, children's vocabulary was significantly larger than in groups where signs were hardly implemented (Schüler et al., 2021). Moreover, sign learning correlated positively with spoken language development: children with better language skills learned significantly more signs than children with lower language skills.

### Sign use in deaf and hearing preschool children in interactions

Concerning interactions, there are studies from different kindergarten settings often focusing on different aspects such as educator–child or peer interactions, children's language profiles, and language modality. Modality is the channel through which language is produced and received, i.e., spoken languages *via* the auditory-vocal modality and sign languages *via* the visual-gestural modality (Meier et al., 2009). In kindergarten settings, where only spoken language is used, it is particularly challenging to join interactions for children with language development delays or hearing loss (Guralnick et al., 1996; Odom et al., 2002; Preisler et al., 2002; DeLuzio and Girolametto, 2011). Therefore, some studies investigated the effect of sign use by hearing educators on children's modality use in educator-child interactions. The hearing children with and without disabilities in DiCarlo et al.'s study showed increased communication in both speaking and signing in hearing educator-child interactions (DiCarlo et al., 2001). Wijkamp et al. (2010) observed an increase in the use of gestures or signs in educator-child interactions in some of the children with severe language development delays when they used less spoken language. The children's individual background was driving this effect. Overall, the study observed a large increase in gestures but only a small increase in sign production within hearing educator-child interactions (Wijkamp et al., 2010). Preisler et al. (2002) investigated interactions between deaf children with cochlear implants and their educators in kindergarten settings for deaf and hard of hearing children (DHH) in which speech and signs were used. In these educator–child interactions, speech was used predominantly and often supported by signs. They reported that conveying linguistic content was more difficult when more speech without signs was used. But when the educators ensured eye contact with the children and clearly conveyed the context, the children understood simple instructions. In contrast, in deaf children with cochlear implants from a kindergarten setting for deaf children with educators using sign language, Preisler et al. (2002) observed extensive and abstract communication in educator–child interactions.

In terms of peer interactions, there are a few more studies available investigating communicative interactions between DHH children, children with language development delays and their typically developing hearing peers. Peer interactions are important for children to learn social skills and are critical contributors to social development (Corsaro, 1997, 2013; Antia et al., 2011). Paying attention to language development delays is particularly important as they were found to be a risk factor for being excluded from peer interactions in the auditory-vocal modality (Guralnick et al., 1996, 2006; Odom et al., 2002). In kindergarten groups with only deaf children where sign language was used, Preisler et al. (2002) reported that deaf children with cochlear implants used sign language at an age-appropriate level in peer interactions. In contrast, for DHH children in an auditory-vocal mainstream setting, DeLuzio and Girolametto (2011) observed consistent with previous studies (Arnold and Tremblay, 1979; Antia et al., 1993; Minnett et al., 1994; Spencer et al., 1994; Brown et al., 2000) that they received fewer interaction requests from hearing peers than their hearing peers and that DHH children's initiation attempts were responded to less frequently by their peers than for hearing children. Overall, many studies report that not only entering in interactions, but also maintaining them is challenging for deaf children in auditory-vocal settings (for an overview see Xie et al., 2014). However, study results differ depending on factors such as the children's and their interlocutor's language ability and mode of communication, their familiarity, or age (see Antia et al., 2011). In preschools for DHH children where spoken language with supporting signs was used, Preisler et al. (2002) found children without sign language competencies to communicate mainly using pointing, gestures, or eye-contact. Similarly, Antia et al. (1993) describe that hearing and DHH children using oral or total communication interact mainly using gestures, exchanging objects, or playing games without verbal communication with each other. Furthermore, children with developmental language delays or hearing loss are reported to communicate more with educators and less with peers in comparison to the age-matched hearing children (Kniel and Kniel, 1984; Odom et al., 2002; Antia et al., 2011). Interacting primarily with educators is also reported by Preisler et al. (2002) for deaf children attending a mainstream setting with a sign language competent assistant. These deaf children enrolled in mainstream kindergarten groups primarily interacted with the sign language competent assistant. In peer interactions during play, these deaf children were observed to take over only non-communicative roles. However, this study examined a setting with hearing sign language competent assistants that were primarily translating between sign and spoken language, rather than deaf professionals communicating in sign language in all interactions. In addition, due to the study design, most of the data were collected during activities initiated by adults, such as telling stories, but not during free play.

## Modality use in bimodal-bilingual kindergarten settings

In bimodal-bilingual settings, all children are offered sign and spoken language and, thus, two modalities are available for hearing and DHH children to communicate. A study by Schulz (2016) focused exclusively on peer interactions in a bimodal-bilingual preschool group with hearing and DHH children. Although children were reported to use both modalities, most children could be assigned to a specific language group (Schulz, 2016): The hearing children communicated predominantly with other hearing children in spoken language, whereas the DHH children communicated predominantly with other DHH children in sign language. Preferring peers with the same hearing status for interaction is consistent with previous research (e.g., Arnold and Tremblay, 1979; Antia et al., 1993; Minnett et al., 1994; Spencer et al., 1994; for an overview see Antia et al., 2011). Ardito et al. (2008) similarly reported sign language use in deaf and hearing children in a bimodal-bilingual preschool group, where hearing educators used spoken language accompanied with signs and deaf educators used sign language. They suggested that the deaf and hearing children not only showed progress in their literacy development, but also developed better skills in both languages, signed and spoken. To the best of our knowledge, there is no study examining modality use in peer interactions in a bimodal-bilingual setting with both deaf and hearing educators, but with only one deaf child. The question arises how communication is shaped when only one deaf child is present in a bimodal-bilingual setting. Moreover, there is a lack of studies examining sign learning and its use in hearing children with and without language development delays when a deaf educator acts as a sign language role model. A co-enrollment setting of deaf and hearing children, especially including children with language development delays, offers a unique opportunity to investigate language and communication in all children. But to what extent do children learn and use signs in a setting with a deaf educator and a deaf child? How do factors such as a child's level of spoken language development affect sign learning and its use in interactions during free play? Free play is an important setting for the participation in social peer interactions which are essential during child development (Corsaro, 1997). However, there is hardly any data available so far for learning settings of social and cultural processes (Corsaro, 2013) in a co-enrollment setting with a deaf child.

Therefore, our study used questionnaire and video data to examine the sign learning and use of children in an inclusive kindergarten group into which a deaf child was co-enrolled simultaneously with a deaf educator six months before data collection, so that a bimodal-bilingual setting was established. In this study, a bimodal-bilingual setting refers to an environment in which at least one deaf educator communicates with all children in sign language while at least one hearing educator communicates in spoken language, accompanied in part by signs. The children in our sample are supervised by one deaf educator and several hearing educators. Our data will be directly contrasted with data from inclusive kindergarten groups with hearing educators of Schüler et al. (2021). This comparison of sign learning in children with and without language development delays under different input conditions allows for a more extended assessment of role modeling as an influential factor on children's sign learning. Following Schüler et al. (2021), we also investigated the correlation between hearing children's spoken language abilities and their sign learning. In addition, the data are analyzed to determine the use of different modalities in interactions during free play in order to assess which participation opportunities such a co-enrollment setting offers to children with different language learning prerequisites.

# Materials and methods

## Participants

In total, 12 children (seven boys and five girls) from a co-enrollment kindergarten group participated in this study (for detailed participant background information, see Table 1 in the results section). Eleven children were hearing (age range = 3;7–5;9 years, *M* age = 4;5 years). Eight of them were monolingual native German speakers while three were bilingual with German as one of their languages. One child (age = 3;8 years) was a third generation deaf native signer acquiring German Sign Language (DGS) from birth from her deaf parents. All children included in the study had been attending the group for at least six months with the deaf child being co-enrolled in the group exactly six months ago. At that time, a deaf signing educator exposed to signs since the age of six years and using DGS as primary mode of communication since the age of 12 years, was employed in the group in parallel. Three hearing children received at least one kind of therapy like speech therapy, ergotherapy or physical therapy, but mostly in combination. Of these three children, one child was diagnosed with epilepsy affecting the speech center, one child had been described as having three detected genetic defects influencing cognitive and motoric development and one child had no diagnosed disability but showed a language delay in German and received ergotherapy. Additional six children of the same preschool group were excluded from the study due to enrollment of less than six months prior to data collection ($n = 5$) or with complex disabilities preventing the acquisition of sign or spoken language ($n = 1$). Participants' legal guardians provided written informed consent prior to participation in the study.

## Materials

In this study, we used the combination of questionnaire and video recordings to tackle our research question. The questionnaire was answered by both parents and educators and comprised four different sections with demographic information being provided at the beginning of the questionnaire prior to the sections (see Supplementary Material A for the educator questionnaire). The first section assessed vocabulary knowledge in sign and spoken language by presenting parents and educators with a list of 94 words and signs and ask them to mark each word and sign that the child is actively producing as a word and as a sign separately. This list contained 82 items extracted from the German language screening test SBE-3-KT (Suchodoletz et al., 2011) and an additional set of 12 signs and their corresponding translation equivalents from Schüler et al. (2021) often used in kindergarten communication settings and, thus, allowing for a direct comparison of both studies. The second section included 15 items from the grammar section of the SBE-3-KT test to measure children's language developmental status more extensively. The next section collected information on the use of modalities in interactions with educators and peers overall to analyze children's pragmatic-communicative skills. These questions were adapted from the Pragmatic Profile by Dohmen (2009) with sign and sign language as additional response options. Finally, the last section required the rating of each child's speech intelligibility and comprehension on a scale of 0–100 in full numbers to better assess their abilities in spoken communication.

In addition, video data were collected during free play sessions in order to analyze language and modality use during interactions. A total of 13 cameras were installed in the rooms so that the children's interactions could be recorded in all areas as far as possible. One hour of free play was filmed for each of the two survey days per child.

## Analysis

### Questionnaire data

The spoken vocabulary and grammar part was evaluated following the given procedure of the SBE-3-KT (Suchodoletz et al., 2011). We evaluated only the questionnaires completed by the educators as these are considered more reliable than the parents' questionnaires because the educators are more familiar with the signs presented in the questionnaire and their answers are more closely related to the kindergarten setting. For each child, a sign score

TABLE 1 Demographic data, SBE-3-KT-score and sign score of the children sorted by hearing level, age of German acquisition and speech therapy.

| Child no. | Gender | Age in months | Individual background | Therapy | Language | SBE-3-KT score (max. 172) | Sign score (max. 94) | Speech intelligibility in % | Speech comprehension in % |
|---|---|---|---|---|---|---|---|---|---|
| *Hearing children without speech therapy and German acquisition from birth* | | | | | | | | | |
| 1 | M | 44 | – | – | German, Polish | 118 | 2 | 60 | 70 |
| 2 | F | 45 | – | – | German | 153 | 17 | 75 | 90 |
| 3 | M | 50 | – | – | German | 172 | 9 | 90 | 100 |
| 4 | F | 52 | – | – | German | 172 | 30 | 100 | 100 |
| 5 | M | 54 | – | Ergotherapy | German, Arabic | 39 | 3 | 30 | 30 |
| 6 | M | 55 | – | – | German | 171 | 10 | 100 | 100 |
| 7 | M | 57 | – | – | German | 172 | 7 | 100 | 90 |
| 8 | F | 64 | – | – | German | 172 | 31 | 100 | 100 |
| *Hearing child without speech therapy and successive acquisition of German* | | | | | | | | | |
| 9 | M | 53 | – | – | Croatian, English, German (starting at 3 months) | 124 | 35 | 75 | 80 |
| *Hearing children with speech therapy* | | | | | | | | | |
| 10 | F | 43 | Epilepsy (caused by FCD or ganglioglioma), speech center affected | Speech therapy, ergotherapy | German | 6 | 17 | 50 | 90 |
| 11 | M | 69 | Three detected genetic defects | Speech therapy, ergotherapy, physical therapy | German | 144 | 0 | 70 | 70 |
| *Deaf child* | | | | | | | | | |
| 12 | F | 44 | Sensory-neural deafness | Speech therapy, ergotherapy | DGS, German | – | 93 | 10 | 0 |

and an SBE-3-KT score was calculated. For the sign score, each sign of the list presented in section one of the questionnaire marked as used by the child more than once was assigned one point leading to a maximum score of 94. In the evaluation of the spoken language part, a total of up to 172 points could be achieved.

First, we compared the sign score of the 11 hearing children from our co-enrollment group with the data of Schüler et al. (2021) using similar materials. They analyzed the sign learning of 289 children from inclusive kindergarten groups with only hearing educators who were trained in using signs six months prior to data collection. The children were divided into two groups based on implementation strength: One group consisted of 145 children (age range = 2;1–6;3 years, *M* age = 4;4 years), whose educators used signs frequently, i.e., high implementation strength. The other group comprised 144 children (age range = 1;7–6;6 years, *M* age = 4;4 years), whose hearing educators used signs rarely, i.e., low implementation strength (for a detailed description of the participants demographic data see Supplementary Material B). As the Shapiro–Wilk test revealed no normal distribution of the data ($W = 0.76$, $p < 0.001$), we used a nonparametric Kruskal–Wallis to test for the effect of group. A *post hoc* Wilcoxon rank-sum test with the Holm method for value of p adjustment (Holm, 1979) was applied to compare the sign score of our co-enrollment group to the two implementation groups of Schüler et al. (2021). In parallel to Schüler et al. (2021), we investigated the correlation between the sign score and the SBE-3-KT score. For this purpose, we calculated the non-parametric Kendall's rank correlation $\tau$ for all 11 hearing children displayed in a scatterplot in the results section.

Regarding the pragmatic profile, we only evaluated the four questions that concern the children's active use of a modality during interactions to get an impression of children's modality use over time from the educator's perspective. The first three questions relate to educator-child interactions and the fourth question relates to peer interactions (for details, see the Supplementary Material A).

### Video data

The video data were coded with respect to language use and interactions motivated by Preisler et al. (2002) and Schulz (2016) (see Supplementary Material C for further information on the coding scheme). Of all video data, 30 min of each child were coded from two survey days resulting in a total of 60 min of coded free play per child. All children were present on the same two survey days, except for children 9, 10, and 11. As child 10 and 11 were not present on one of these survey days, videos from another day were coded for these children. Child 9 was not present on this other day; thus, the child was excluded from the video analysis.

For each interaction, children's interaction partners were determined, and modalities used by the children and their interaction partners were coded including spoken language, sign language, code-blending, code-switching, and nonverbal communication strategies such as pointing, nodding, head shaking, laughing, giving or taking objects. Nonverbal communication was only selected when no lexicalized words or signs occurred within the coded interaction and, thus, none of the other categories applied. Code-blending was selected when spoken words and signs were produced simultaneously, even if this happened only once within an interaction. In contrast, code-switching was assigned if a child switched from spoken language to sign language or vice versa. The videos were coded by two student assistants who are hearing advanced signers and had previously been trained in a similar coding scheme during a previous project (Goppelt-Kunkel et al., 2021). To determine consistency during coding, a reliability analysis was performed on 20% of the data from five randomly selected children, including the deaf child, using Cohen's Kappa (Cohen, 1960). Coders show substantial agreement for coding used modalities ($\kappa = 0.74$, 95% CI [0.55, 0.94]).

## Results

### Sign score and SBE-3-KT score

Table 1 below presents an overview of the sign score and the SBE-3-KT score as well as additional demographic information for each child in the co-enrollment group.

First, we assessed sign learning in the hearing children across all groups, i.e., in the co-enrollment group and the two implementation groups from Schüler et al. (2021) showing a main effect for group [$\chi^2(2) = 130.51$, $p < 0.001$, $\eta^2 = 0.43$]. Follow-up tests comparing the low implementation group, i.e., group 1 (sign score $M = 1.09$), and the high implementation group, i.e., group 2 (sign score $M = 7.09$), each with our co-enrollment group, i.e., group 3 (sign score $M = 14.64$), revealed significant differences. The average sign score of the hearing children in the co-enrollment group was significantly higher than in implementation group 1 ($p < 0.001$, $d = 0.39$) and implementation group 2 ($p = 0.05$, $d = 0.16$) from Schüler et al. (2021) as shown in Figure 1.

Next, we analyzed the relationship between the sign score and the level of language development in spoken language in the hearing children of our co-enrollment group. Children's sign score and SBE-3-KT score correlated weakly for the hearing children ($r_\tau = 0.117$, $p = 0.630$) but did not reach statistical significance. The data visualization in Figure 2A suggested that the two children undergoing speech therapy and the one child that did not acquire German from birth showed diverging patterns in the relationship between sign score and language development level. Therefore, we excluded these three children and repeated the correlation analysis (Figure 2B). When only including children, who learned German from birth and who did not show a language development delay ($n = 8$), the correlational coefficient increased to medium ($r_\tau = 0.403$, $p = 0.184$) but still the correlation did not reach significance even if a tendency toward significance can be observed. The lack of significance might be due to the very small sample size of our group and, thus, with a larger more homogenous sample significance might be reached. Nevertheless, the observed direction of the correlation in our data is consistent with Schüler et al. (2021) showing higher sign learning for children with advanced spoken language skills. Thus, irrespective of the tested group, a higher SBE-3-KT score seems to condition a higher sign score.

### Pragmatic profile

In educator-child interactions, hearing children without speech therapy and acquiring German from birth were all reported to use spoken language in complete sentences with some exceptions of single words, two-word sentences, or other modalities (for a summary presentation of the data, see Table 2). Child 4 additionally used sign language in one of the three queried situations. Child 5 did not use full sentences, but single words, two-word combinations or nonverbal communication strategies. Child 7 used, depending on the situation, complete sentences, single words or two-word combinations, signs, or used no language, but reacted emotionally with crying or anger. The two hearing children undergoing speech therapy used diverging modalities for communication: Child 10 used nonverbal communication strategies, reacted with emotions, used single signs, or single words depending on the communication context. Child 11 used single words or pointed to a desired object. The deaf child used sign language.

For participating in peer interactions, hearing children without speech therapy and acquiring German from birth were all reported to use spoken language (for a summary presentation of the data, see Table 3). Additionally, child 8 used a combination of words and signs and child 4 played next to other children without communicating with them. Child 9 that did not learn German from birth also communicated in spoken language in peer

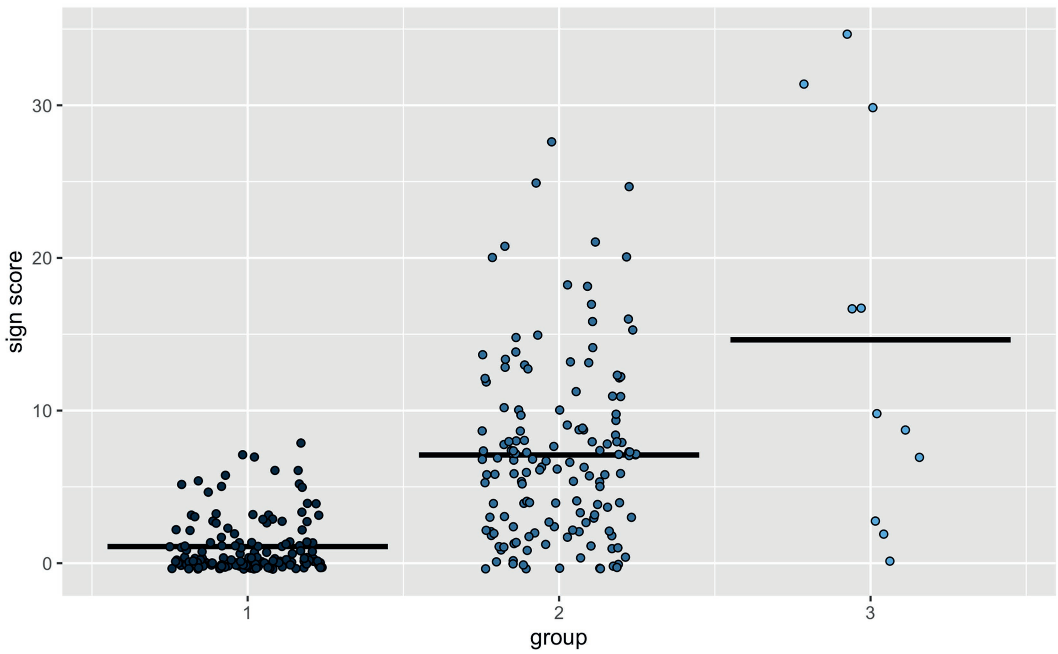


FIGURE 1
Sign score for hearing children by groups with (1) the inclusive kindergarten groups with low implementation of signs from Schüler et al. (2021), (2) the inclusive kindergarten groups with high implementation of signs from Schüler et al. (2021) and (3) the co-enrollment group with a deaf child and a deaf educator.

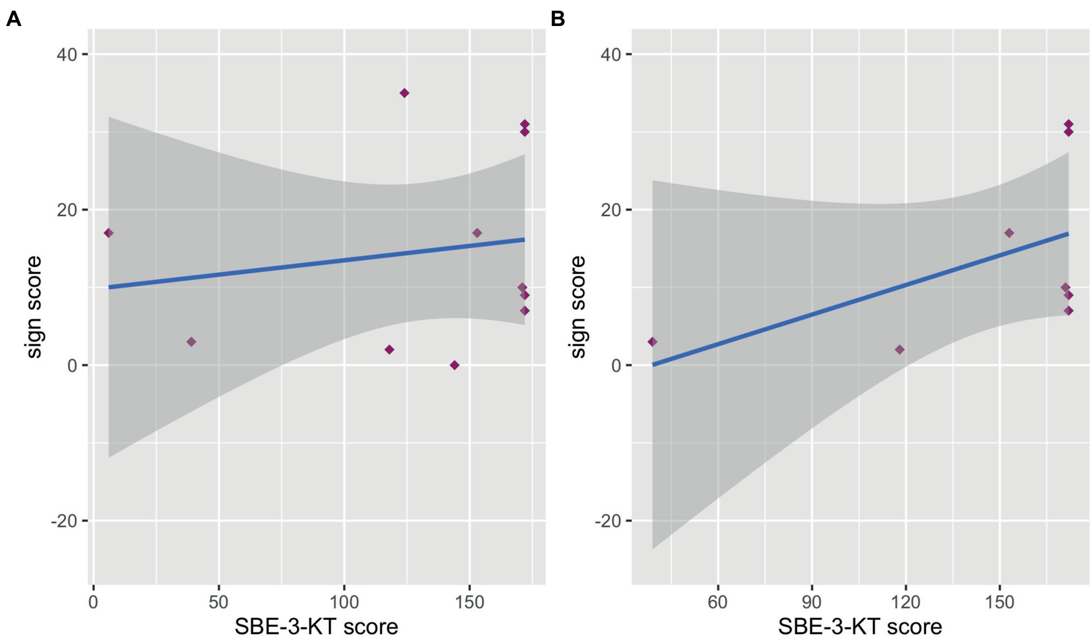


FIGURE 2
Correlation between sign score and SBE-3-KT-score for the co-enrollment group for (A) all hearing children and (B) only hearing children acquiring German from birth and without speech therapy.

interactions. Child 10 who was undergoing speech therapy due to epilepsy used a combination of words and signs for peer interactions or played parallel to other children without communicating with them. Child 11 who was undergoing speech therapy due to genetic defects used spoken language for peer interactions or played by himself, thus without communicating

TABLE 2 Active use of modalities and communication strategies for each child in interactions with educators as indicated in the respective section of the educator questionnaire.+

| Child | Spoken language | Sign language | Spoken language and sign language | Nonverbal communication (e.g., mimic or gestures) | Emotional/passive reaction (e.g., crying) |
|---|---|---|---|---|---|
| Child 1 | + | – | – | + | – |
| Child 2 | + | – | – | – | – |
| Child 3 | + | – | – | – | – |
| Child 4 | + | + | – | + | – |
| Child 5 | + | – | – | + | – |
| Child 6 | + | – | – | + | – |
| Child 7 | + | + | – | + | + |
| Child 8 | + | – | – | + | – |
| Child 9 | + | – | – | + | – |
| Child 10 | + | + | – | + | + |
| Child 11 | + | – | – | + | – |
| Child 12 | – | + | – | – | – |

A "+" indicates that the modality was selected for the child for at least one question.

TABLE 3 Active use of modalities and communication strategies for each child in peer interactions.+

| Child | Spoken language | Sign language | Spoken and sign language | Playing alone | Playing alongside the other children | Watching the other children | Need of adult guidance |
|---|---|---|---|---|---|---|---|
| Child 1 | + | – | – | – | – | – | – |
| Child 2 | + | – | – | – | – | – | – |
| Child 3 | + | – | – | – | – | – | – |
| Child 4 | + | – | – | – | + | – | – |
| Child 5 | + | – | – | – | – | – | – |
| Child 6 | + | – | – | – | – | – | – |
| Child 7 | + | – | – | – | – | – | – |
| Child 8 | + | – | + | – | – | – | – |
| Child 9 | + | – | – | – | – | – | – |
| Child 10 | – | – | + | – | + | – | – |
| Child 11 | + | – | – | + | – | – | – |
| Child 12 | + | – | – | – | – | – | + |

A "+" indicates that the educators observed the respective modality.

with other children. The deaf child was reported to use indistinct spoken language toward peers for playing and to need help by educators to join peer interactions.

## Video data

Overall, 1,254 interactions of all 11 children were coded with 193 educator-child interactions (15.4%) and 1,061 peer interactions (84.6%). Table 4 below provides an overview of all interactions separated by used modality and interaction partner.

Hearing children were involved in 1,169 interactions and mostly interacted with their peers and less with the educators except for child 10, who was undergoing speech therapy. In interactions with hearing educators, the hearing children primarily used spoken language followed by nonverbal communication strategies and rarely code-blending. However, the two hearing children undergoing speech therapy, children 10 and 11, mainly used nonverbal communication strategies with their educators followed by spoken language. The four code-blending interactions were all observed in children with delayed spoken language development in German toward hearing educators, two in child 10, one in child 11 and one in child 5. When communicating with the deaf educator, the hearing children relied on nonverbal communication strategies but less on spoken language. In peer interactions, hearing children used predominantly spoken language followed by nonverbal communication strategies. In contrast, the children undergoing speech therapy mainly used nonverbal communication strategies for peer interactions but also spoken language. Code-blending and sign language were only applied in a few cases by hearing children while code-switching was not observed. The two peer-interactions with code-blending

TABLE 4 Occurrences of language modalities as percentages with absolute numbers in parentheses used by the hearing children and the deaf child when interacting with hearing educators, the deaf educator, hearing peers or the deaf peer in the video data.

| Interactions | Spoken language | Nonverbal communication | Code-blending | Code-switching | Sign language | Total |
|---|---|---|---|---|---|---|
| *Hearing children* | | | | | | *93.2%* |
| | | | | | | *(1169)* |
| Hearing educator | 54.3% | 42.2% | 3.4% | 0% | 0% | 9.9% |
| | (63) | (49) | (4) | (0) | (0) | (116) |
| Deaf educator | 23.1% | 76.9% | 0% | 0% | 0% | 1.1% |
| | (3) | (10) | (0) | (0) | (0) | (13) |
| Hearing peer | 72.4% | 27.4% | 0.2% | 0% | 0% | 87.7% |
| | (742) | (281) | (2) | (0) | (0) | (1025) |
| Deaf peer | 13.3% | 80.0% | 0% | 0% | 6.7% | 1.3% |
| | (2) | (12) | (0) | (0) | (1) | (15) |
| *Deaf child* | | | | | | *6.8%* |
| | | | | | | *(85)* |
| Hearing educator | 4.3% | 43.5% | 8.7% | 8.7% | 34.8% | 27.1% |
| | (1) | (10) | (2) | (2) | (8) | (23) |
| Deaf educator | 0% | 36.6% | 0% | 0% | 63.4% | 48.2% |
| | (0) | (15) | (0) | (0) | (26) | (41) |
| Hearing peer | 14.3% | 66.7% | 0% | 0% | 19.0% | 24.7% |
| | (3) | (14) | (0) | (0) | (4) | (21) |

were observed in two hearing children without disabilities, child 7 and 8, both with child 4 without disabilities. The only observed interaction in which sign language was used by a hearing child was detected in child 5 when communicating with the deaf child.

The deaf child participated in 85 interactions predominantly with the educators and comparatively less with her peers. Communicating with educators, the deaf child predominantly interacted with the deaf educator mostly using sign language and, in fewer cases, nonverbal communication strategies. In contrast, interactions with the hearing educators were much less and the pattern of used modalities was reversed with additional observed modalities. The deaf child primarily used nonverbal communication strategies and sign language whereas spoken language, code-blending, and code-switching were only used in a few interactions. In interactions with her hearing peers, the deaf child applied mostly nonverbal communication strategies but also used sign language and spoken language.

# Discussion

In our study, we investigated sign learning in hearing children and language modality use of hearing children and a deaf child in a co-enrollment kindergarten setting. The deaf child was co-enrolled six months before data collection in parallel with a deaf educator. We observed that hearing children in the co-enrollment setting had learned significantly more signs than children from inclusive day care centers whose hearing educators had learned signs in a training program (Schüler et al., 2021). Children with more advanced spoken language skills demonstrate a tendency to higher sign scores except for children with certain individual backgrounds or later acquisition of German, although this observation did not reach significance possibly due to the small sample size. In interactions during free play, however, hearing children used predominantly spoken language. The deaf child used predominantly sign language with the deaf educator and predominantly nonverbal communication strategies with hearing educators and her peers. Code-blending was observed only occasionally, mostly by children with language development delays when communicating with hearing educators. Code-switching, on the other hand, was observed sporadically only in the deaf child when communicating with hearing educators.

## Sign learning

The analysis of sign learning revealed that the hearing children in our co-enrollment group with a deaf educator learned signs. Compared with data from children of inclusive day care groups with sign-trained hearing educators (Schüler et al., 2021) children in our co-enrollment group showed a significantly higher sign score. This difference seems not to arise due to different language development levels of the children, since the children from Schüler et al.'s groups with low sign scores showed the highest spoken language skills whereas the hearing children from the co-enrollment group showed the lowest spoken language skills. The major difference between our co-enrollment group and Schüler et al.'s groups is the presence of a deaf educator. The deaf educator and the deaf child are communicating predominantly using sign language, and, therefore, the co-enrollment group is exposed to the signed modality more extensively presumably leading to increased sign learning. This suggests that hearing children might learn more signs due to deaf role models. However, we cannot exclude previous occasional sign contact since the deaf child attended another group of this kindergarten before enrollment in the observed group and another deaf child in a different group attended the kindergarten two years ago. But, comparing the sign score of the co-enrollment group with the sign score of the children in the groups of hearing sign trained educators after 18 months of exposure in the data of Schüler and Hänel-Faulhaber (n.d.) suggests that even with prolonged contact with signs by hearing educators children seem to learn less signs as when a deaf role model is present.

Furthermore, we observed that hearing children's sign learning showed a tendency to correlate positively with their spoken language abilities. However, this relation does not become significant in our data. Nevertheless, applying the analysis to a more homogeneous group by excluding children with language development delays and onset of German acquisition later than birth, the relation increases. The general tendency of this relation is in line with Schüler et al. (2021) who show that children with more advanced spoken language skills learned more signs than children with less advanced spoken language skills. The lack of significance might be due to the small sample size or the used test to assess the spoken language abilities as all hearing children are almost at ceiling. The SBE-3-KT was selected to compare our data with the data of Schüler et al. (2021), but for a more accurate calculation of the correlation between sign learning and spoken language abilities tests normed for the investigated age group are required. Nevertheless, this correlation is also reported for unimodal bilingual preschool settings and explained by increasing abilities to process language (*cf.*, Wode, 2009). However, in our small and heterogenous sample, we observed children with different patterns: The child with epilepsy, whose speech center was affected, had learned more signs than all other hearing children on average despite the lowest score in the spoken language test. This suggests that the child was able to use unaffected brain areas for language *via* the visual modality. This is supported by similar observations in children with Down syndrome (Kay-Raining Bird and Chapman, 1994; Kay-Raining Bird et al., 2000) and with autism spectrum disorders (O'Connor, 1971). Thus, a visual language provided the opportunity for more and improved communication with implications for other areas of development such as social–emotional and cognitive skills. However, the other child undergoing speech therapy did learn no sign from the tested list. This reveals that sign learning may depend on the individual background of a child with language development delay. The one child that did not learn German from birth and showed no age-appropriate language skills in German, had learned most signs of the tested list. Therefore, we assume that this child also benefited in a special way from the visual modality. It might be the case that the visual modality offered the opportunity to see aspects of the referents represented iconically (Lüke and Ritterfeld, 2014; Vogt and Kauschke, 2017). However, the other bilingual children with delayed language development in German learned fewer signs than all other hearing children in the co-enrollment group. This suggests that only some bilingual children show a preference for learning signs which might be driven by the age of acquisition of the national language as found by Schüler and Hänel-Faulhaber (n.d.). However, the child with successive acquisition of German of our co-enrollment group started to acquire German at the young age of three months, thus, being exposed to three languages or other factors might have been more crucial for his high sign score. Overall, our co-enrollment group's heterogeneity provided the opportunity to observe different patterns of sign learning and modality use, but our findings need to be investigated in more depth in future studies with a larger and more controlled group of children.

## Modality use in interactions

Despite acquiring signs, hearing children in our study rarely used the visual modality in interactions and mostly interacted in spoken language instead. This finding is consistent with research from inclusive kindergarten groups whose educators were trained to use signs in interactions with children (Goppelt-Kunkel et al., 2021). Similar findings were reported from monomodal-bilingual kindergarten settings showing that children mostly communicate in the national language unless there is a need to use the second language offered (*cf.*, Wode, 2009).

In interactions with educators, two hearing children without disabilities sometimes used signs according to the questionnaire data, but in the video data sign use toward educators by hearing children was observed only for hearing children with language development delays: They sporadically used code blending in interactions with a hearing educator. Furthermore, in interactions with hearing educators, hearing children predominantly used spoken language. This finding is not surprising, as spoken language is the national language and the main mode of communication for both. In contrast, when communicating with the deaf educator, hearing children were never observed to use sign language or signs but mainly used nonverbal communication strategies and sometimes spoken language. This observation might be surprising because children at this age are expected to be aware of which language their interaction partners use (Petitto et al., 2001), however, this was observed in children growing up bimodal-bilingually from birth. In contrast, factors like language dominance and sociolinguistic context induce the use of the national language for active communication in bilingual children irrespective of their interlocutors´ language (Paradis and Nicoladis, 2007; see Müller et al., 2011 for an overview). This is reported for children acquiring a second language in a monomodal bilingual kindergarten setting as well (Wode, 2009). Our findings are in line with these observations. Additionally, it might be the case that the hearing children just do not have sufficient sign language skills yet to use signs in interactions.

In peer interactions, signs were barely used by hearing children as well: According to the questionnaire data, only two hearing children used a combination of words and signs, the child with language development delay due to epilepsy and one child without disabilities and growing up monolingually. This reveals that the child with epilepsy could communicate better with signs in some situations and, thus, could participate more easily in interactions. Therefore, this child benefited from the signs introduced in the group as indicated by richer sign than spoken vocabulary and the use of the visual modality for communication with both, educators and children. Using signs may have enabled that child to compensate for spoken language skills that were more challenging to acquire because of her individual background. Thus, a visual language may have been another way to participate in interactions. This assumption is additionally supported by the data from other children with language development delays who sporadically used mixed modalities in communication with hearing educators of our co-enrollment group and is consistent with Goppelt-Kunkel et al. (2021) as well. However, in peer interactions during the analyzed free play, the children undergoing speech therapy did not use signs at all but mainly nonverbal communication strategies and, rarely, spoken language. Perhaps, despite their limited spoken language skills, these children tried to communicate with the other hearing children in the language most used by them, the national language, consistent with observations in bilingual kindergarten settings (Wode, 2009). Additionally, please keep in mind that the child with epilepsy was present on only one of the two survey days when the deaf child was present, so that only half of the video data did allow for common interactions with the deaf child mainly interacting in sign language. The hearing child who was reported to use signs in peer interactions might use signs depending on its interaction partners. However, this is not observed in the video data. The only child that used sign language in a peer interaction with the deaf child in the video data was a different child receiving ergotherapy, growing up bilingually and showing a language development delay. This rare use of the visual–spatial language modality by hearing children makes almost all peer interactions between hearing children linguistically inaccessible to the deaf child.

The deaf child predominantly interacted with educators, especially with the deaf educator, consistent with the observations in Preisler et al. (2002) reporting this for mainstream settings with sign language competent assistants. For interactions with the deaf educator, the child predominantly used sign language, whereas with hearing educators, she predominantly used nonverbal communication strategies and somewhat less sign language. This suggests that the deaf child shows sensitivity to the educator's language and, therefore, adapts to the educator's language skills as described in Petitto et al. (2001). In peer interactions, according to the video data, the deaf child used mainly nonverbal communication strategies, occasionally sign language, and somewhat less frequently spoken language. Again, the deaf child presumably assesses the hearing peer's language skills and chooses the most successful way to participate in interactions. With predominantly nonverbal communication, the peer communication behavior of the deaf child in the co-enrollment group less resembles bimodal-bilingual settings with DHH peers communicating in sign language but is rather comparable with observations from settings with speech accompanying signs or mainstream settings with hearing sign language assistants (Preisler et al., 2002; Antia et al., 2011; Schulz, 2016). But these settings lack age-appropriate language peers for deaf children to interact with. Thus, in addition to sign language input provided by educators, the presence of other DHH children seems to be crucial for the use of sign language in peer interactions with age-appropriate language (Spencer et al., 1994; Preisler et al., 2002; Ardito et al., 2008). Furthermore, the educators reported in the questionnaire that the deaf child needed assistance of adults to get involved in playing with other children and communicated in indistinct spoken language with them. The need for adult assistance to participate in peer interactions is consistently reported for deaf children in mainstream settings with sign language competent assistants (Preisler et al., 2002). So, six months after enrollment, the deaf child did not have equal chances to participate in interactions during free play as her hearing peers almost exclusively communicated in the auditory-vocal modality. Therefore, joining ongoing interactions seemed to be particularly challenging for the deaf child, even though it might be the case that some children already had prior knowledge of signing. As an additional factor, we need to consider that the deaf child was one of the youngest children in the group and peer-interaction is known to increase with age (Rubin et al., 1998). It must also be kept in mind that for DHH children in particular, time and familiarity with their peers seem to be important factors that might improve interactions (Lederberg et al., 1986; Kurkjian and Evans, 1988; Rodríguez and Lana, 1996). Nonetheless, more sign language competent peers are needed, as it is known from previous research that this is an important prerequisite for age-appropriate communication between peers (Preisler et al., 2002) also in a bimodal-bilingual setting (Ardito et al., 2008). Furthermore, language planning and modality planning, i.e., designated rooms or times in which communication is required exclusively in the visual modality, could increase the sign use of hearing children. On the one hand, this concept requires focused attention of the hearing children on the visual modality and, on the other hand, might lead to increased sign language skills in these children for peer interactions.

## Limitations

The heterogenous group in our study provided a unique opportunity to examine the sign learning and use of deaf and hearing children with and without disabilities in a bimodal-bilingual kindergarten setting with a deaf educator and hearing educators. But investigating this small co-enrollment sample also led to some limitations: The small sample size limited the statistical power of the comparison of the sign scores of the hearing children of our co-enrollment group with the sign scores of groups with only hearing educators from Schüler et al. (2021) as well as of the reported correlation exploring the relation between sign score and spoken language skills. Future studies should include a more homogenous group and an increased sample size.

Furthermore, the test used to assess the spoken language skills might not reflect individual differences in our data sufficiently. The SBE-3-KT was used to allow for a direct comparison with the data from Schüler et al. (2021), however, the test is normed for children from 32 to 40 months. Therefore, future studies with more age-appropriate spoken language assessments are needed in order to more accurately capture the relation between sign learning and spoken language abilities in bimodal-bilingual kindergarten settings.

Another restricting factor could be previous sign knowledge of the hearing children. It cannot be ruled out that some children had contact with signs prior to the hiring of the deaf educator since the deaf child attended another group within the same kindergarten before enrollment in the observed group. Moreover, another deaf child attended the kindergarten two years ago, but in a different group. However, data from Schüler and Hänel-Faulhaber (n.d.) suggest that time of sign exposure might have less impact on sign learning than sign language role modeling. They measured the sign learning of children with and without disabilities 18 months after their hearing educators were exposed to signs and observed a lower sign score than in our co-enrollment group indicating that longer exposure to signs does not lead to such effective sign learning as observed when sign language input is provided by a deaf educator.

Finally, it should be noted that the deaf child is one of the youngest children in the group and peer interaction is known to increase with age as mentioned above. To some extent, the lower number of interactions of the deaf child with other children could also be influenced by this fact. In addition, the deaf child attended the group for a shorter period of time than almost all other children studied. As outlined above, time and familiarity with peers are relevant for interactions of deaf children in particular, therefore, these factors might also have had an influence on the observed peer interactions.

## Conclusion

Overall, we observed that hearing children learned signs, but they barely used these for interactions, not even with deaf interlocutors. This suggests that more sign language input as well as language planning encouraging these children to use sign language are needed. Improving normally developing children's sign language use in interactions is additionally important to increase opportunities for children who use sign language or signs for communication to participate in interactions: In our study, hearing children with language development delays used signs in restricted contexts. In particular for the deaf child, the fact that six months after co-enrollment hardly any signs were used in interactions during free play, especially between peers, limited the possibilities to participate in interactions. In addition to targeted approaches that strengthen the use of the visual modality, the presence of more deaf peers (Spencer et al., 1994; Ardito et al., 2008), and more deaf educators is required. Other factors should be kept in mind such as time to increase both familiarity between children and children's sign language skills.

## Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

## Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

## Author contributions

MG-K and BH-F contributed to the conceptualization and design of the study. MG-K conducted the investigation and wrote the original draft. MG-K and AW performed the formal analysis. MG-K, AW, and BH-F were involved in writing, reviewing, and editing of the manuscript. BH-F supervised and provided funding for the investigation. All authors contributed to the article and approved the submitted version.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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## Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2022.920497/full#supplementary-material

## References


Antia, S. D., Kreimeyer, K. H., and Eldredge, N. (1993). Promoting social interaction between young children with hearing impairments and their peers. *Except. Child.* 60, 262–275. doi: 10.1177/001440299406000307

Antia, S. D., Kreimeyer, K. H., Metz, K. K., and Spolsky, S. (2011). "Peer interactions of deaf and hard-of-hearing children," in *The Oxford Handbook of Deaf Studies, Language, and Education*. eds. M. Marschark and P. E. Spencer (New York, NY: Oxford University Press).

Ardito, B., Caselli, M. C., Vecchietti, A., and Volterra, V. (2008). "Deaf and hearing children: reading together in preschool," in *Studies in Bilingualism*. eds. C. Plaza-Pust and E. Morales-López (Amsterdam: John Benjamins Publishing Company), 137–164.

Arnold, D., and Tremblay, A. (1979). Interaction of deaf and hearing preschool children. *J. Commun. Disord.* 12, 245–251. doi: 10.1016/0021-9924(79)90045-5

Bonvillian, J. D., Nelson, K. E., and Rhyne, J. M. (1981). Sign language and autism. *J. Autism Dev. Disord.* 11, 125–137. doi: 10.1007/BF01531345

Brown, P. M., Remine, M. D., Prescott, S. J., and Rickards, F. W. (2000). Social interactions of preschoolers with and without impaired hearing in integrated kindergarten. *J. Early Interv.* 23, 200–211. doi: 10.1177/10538151000230030901

Chen Pichler, D. (2012). "Acquisition," in *Sign Language: An International Handbook*. eds. R. Pfau, M. Steinbach and B. Woll (Berlin: DeGruyter Mouton).

Cohen, J. (1960). A coefficient of agreement for nominal scales. *Educ. Psychol. Meas.* 20, 37–46. doi: 10.1177/001316446002000104

Corsaro, W. A. (1997). *The Sociology of Childhood*. London: Sage.

Corsaro, W. A. (2013). "Interpretative Reproduktion, Peer-Beziehungen von Kindern und ihr Verlangen nach selbstbestimmter Interaktion," in *Dabeisein ist nicht alle - Inklusion und Zusammenleben im Kindergarten*. eds. M. Kreuzer and B. Ytterhus (Munich/Basel: Ernst Reinhardt Verlag).

DeLuzio, J., and Girolametto, L. (2011). Peer interactions of preschool children With and Without hearing loss. *J. Speech Lang. Hear. Res.* 54, 1197–1210. doi: 10.1044/1092-4388(2010/10-0099)

DiCarlo, C. F., Stricklin, S., Banajee, M., and Reid, D. H. (2001). Effects of manual signing on communicative verbalizations by toddlers with and without disabilities in inclusive classrooms. *J. Assoc. Pers. Sev. Handicaps* 26, 120–126. doi: 10.2511/rpsd.26.2.120

Dohmen, A. (2009). *Das Pragmatische Profil: Analyse Kommunikativer Fähigkeiten von Kindern. ("The Pragmatic Profile: Analysis of children's Communicative Abilities")*. Munich: Urban & Fischer.

Goppelt-Kunkel, M., Schüler, M., and Hänel-Faulhaber, B. (2021). Sign-supported communication in inclusive day care centers: the more you need it the more you use it? in Poster presented at the IASCL conference in Philadelphia.

Guralnick, M. J., Connor, R. T., Hammond, M. A., Gottman, J. M., and Kinnish, K. (1996). The peer relations of preschool children with communication disorders. *Child Dev.* 67:471. doi: 10.2307/1131827

Guralnick, M. J., Hammond, M. A., Connor, R. T., and Neville, B. (2006). Stability, change, and correlates of the peer relationships of young children with mild developmental delays. *Child Dev.* 77, 312–324. doi: 10.1111/j.1467-8624.2006.00872.x

Holm, S. (1979). A simple sequentially rejective multiple test procedure. *Scand. J. Stat.* 6, 65–70.

Kay-Raining Bird, E., and Chapman, R. S. (1994). Sequential recall in individuals With Down syndrome. *J. Speech Lang. Hear. Res.* 37, 1369–1380. doi: 10.1044/jshr.3706.1369

Kay-Raining Bird, E., Gaskell, A., Babineau, M. D., and Macdonald, S. (2000). Novel word acquisition in children with down syndrome. *J. Commun. Disord.* 33, 241–266. doi: 10.1016/S0021-9924(00)00022-8

Kniel, A., and Kniel, C. (1984). *Behinderte Kinder in Regelkindergärten. Eine Untersuchung in Kassel*. Munich: DJI.

Kurkjian, J. A., and Evans, I. M. (1988). Effects of sign language instruction on social interaction Between hearing-impaired and Normal-hearing children. *Child Fam. Behav. Ther.* 10, 121–134. doi: 10.1300/J019v10n02_09

Lederberg, A. R., Ryan, H. B., and Robbins, B. L. (1986). Peer interaction in young deaf children: The effect of partner hearing status and familiarity. *Dev. Psychol.* 22, 691–700. doi: 10.1037/0012-1649.22.5.691

Lüke, C., and Ritterfeld, U. (2014). The influence of iconic and arbitrary gestures on novel word learning in children with and without SLI. *Gesture* 14, 204–225. doi: 10.1075/gest.14.2.04luk

Marschark, M., Schick, B., and Spencer, P. E. (2006). "Understanding sign language development of deaf children," in *Advances in the sign Language Development of Deaf children*. eds. B. Schick, M. Marschark and P. E. Spencer (New York, NY: Oxford University Press), 3–19.

Meier, R. P., Cormier, K., and Quinto-Pozos, D. (eds.) (2009). *Modality and Structure in Signed and Spoken Languages*. Cambridge: Cambridge University Press.

Minnett, A., Clark, K., and Wilson, G. (1994). Play behavior and communication Between deaf and hard of hearing children and their hearing peers in an integrated preschool. *Am. Ann. Deaf* 139, 420–429. doi: 10.1353/aad.2012.0345

Müller, N., Kupisch, T., Schmitz, K., and Cantone, K. (2011). *Einführung in die Mehrsprachigkeitsforschung. 3rd Edn*. Tubingen: Narr Francke Attempto.

Nunes, D. (2008). AAC interventions for autism: a research summary. *Int. J. Spec. Educ.* 23, 17–26.

O'Connor, N. (1971). "Visual perception in autistic children," in *Infantile autism: Concepts, characteristics, and treatment*. ed. M. Rutter (Edinburgh, London: Churchill Livingstone).

Odom, S. L., Zercher, C., Marquart, J., Li, S., Sandall, S. R., and Wolfberg, P. (2002). "Social relationships of children with disabilities and their peers in inclusive preschool classrooms," in *Widening the Circle: Including children With Disabilities in Preschool Programs*. ed. S. L. Odom (New York, NY/London: Teachers College Press), 61–80.

Paradis, J., and Nicoladis, E. (2007). The influence of dominance and sociolinguistic context on bilingual preschoolers' language choice. *Int. J. Biling. Educ. Biling.* 10, 277–297. doi: 10.2167/beb444.0

Petitto, L. A., Katerelos, M., Levy, B. G., Gauna, K., Tétreault, K., and Ferraro, V. (2001). Bilingual signed and spoken language acquisition from birth: implications for the mechanisms underlying early bilingual language acquisition. *J. Child Lang.* 28, 453–496. doi: 10.1017/S0305000901004718

Preisler, G., Tvingstedt, A.-L., and Ahlström, M. (2002). A psychosocial follow-up study of deaf preschool children using cochlear implants: deaf preschool children using cochlear implants. *Child Care Health Dev.* 28, 403–418. doi: 10.1046/j.1365-2214.2002.00291.x

Rodríguez, M. S., and Lana, E. T. (1996). Dyadic interactions Between deaf children and their communication partners. *Am. Ann. Deaf* 141, 245–251. doi: 10.1353/aad.2012.0275

Rubin, K. H., Bukowski, W. M., and Parker, J. G. (1998). "Peer interactions, relationships, and groups," in *Handbook of child Psychology, Volume 3: Social, Emotional, and Personality Development, Fifth edition*. ed. W. Damon (New York, NY: John Wiley & Sons, Inc), 619–700.

Schüler, M., and Hänel-Faulhaber, B. (n.d.). Eine Frage der Notwendigkeit? Follow-up-Untersuchung zum Gebärdenlernverhalten in inklusiven Kindertagesstätten. *Frühe Bild.*

Schüler, M., Stroh, A.-L., and Hänel-Faulhaber, B. (2021). Gebärden in inklusiven Kitas – erste Ergebnisse einer Langzeitstudie. *Sprache Stimme Gehör* 45, 98–102. doi: 10.1055/a-1169-3861

Schulz, L. (2016). Wenn Worte auf Gebärden treffen. Kommunikationsstrategien hörender und hörgeschädigter Kinder im bilingualen Kindergarten. *Zeich.* 104, 396–408.

Spencer, P., Koester, L. S., and Meadow-Orlans, K. (1994). Communicative interactions of deaf and hearing children in a day care center: An exploratory study. *Am. Ann. Deaf* 139, 512–518. doi: 10.1353/aad.1994.0004

Suchodoletz, W. V., Kademann, S., and Tippelt, S. (2011). Sprachbeurteilung durch Eltern–Kurztest für die U7a (SBE-3-KT). ("language assessment by parents - short test for child screening U7a"). Available at: https://www.ph-heidelberg.de/sachse-steffi/professur-fuer-entwicklungspsychologie/elternfrageboegen-sbe-2-kt-sbe-3-kt/sbe-3-kt (Accessed August 2, 2022).

Vogt, S., and Kauschke, C. (2017). Observing iconic gestures enhances word learning in typically developing children and children with specific language impairment. *J. Child Lang.* 44, 1458–1484. doi: 10.1017/S0305000916000647

Wijkamp, I., Gerritsen, B., Bonder, F., Haisma, H., and van der Schans, C. (2010). Sign-supported Dutch in children with severe speech and language impairments: a multiple case study. *Child Lang. Teach. Ther.* 26, 273–286. doi: 10.1177/0265659009349983

Wode, H. (2009). *Frühes Fremdsprachenlernen in bilingualen Kindergärten und Grundschulen*. Braunschweig: Westermann.

Xie, Y.-H., Potměšil, M., and Peters, B. (2014). Children who are deaf or hard of hearing in inclusive educational settings: a literature review on interactions with peers. *J. Deaf. Stud. Deaf. Educ.* 19, 423–437. doi: 10.1093/deafed/enu017

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# Visual attention for linguistic and non-linguistic body actions in non-signing and native signing children

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Evidence from adult studies of deaf signers supports the dissociation between neural systems involved in processing visual linguistic and non-linguistic body actions. The question of how and when this specialization arises is poorly understood. Visual attention to these forms is likely to change with age and be affected by prior language experience. The present study used eye-tracking methodology with infants and children as they freely viewed alternating video sequences of lexical American sign language (ASL) signs and non-linguistic body actions (self-directed grooming action and object-directed pantomime). In Experiment 1, we quantified fixation patterns using an area of interest (AOI) approach and calculated face preference index (FPI) values to assess the developmental differences between 6 and 11-month-old hearing infants. Both groups were from monolingual English-speaking homes with no prior exposure to sign language. Six-month-olds attended the signer's face for grooming; but for mimes and signs, they were drawn to attend to the "articulatory space" where the hands and arms primarily fall. Eleven-month-olds, on the other hand, showed a similar attention to the face for all body action types. We interpret this to reflect an early visual language sensitivity that diminishes with age, just before the child's first birthday. In Experiment 2, we contrasted 18 hearing monolingual English-speaking children (mean age of 4.8 years) vs. 13 hearing children of deaf adults (CODAs; mean age of 5.7 years) whose primary language at home was ASL. Native signing children had a significantly greater face attentional bias than non-signing children for ASL signs, but not for grooming and mimes. The differences in the visual attention patterns that are contingent on age (in infants) and language experience (in children) may be related to both linguistic specialization over time and the emerging awareness of communicative gestural acts.

KEYWORDS

**visual attention, eye tracking, infants, children, sign language, gestures, pantomime, body actions**

## Introduction

Infants start life by being broadly attracted to most language signals (Colombo and Bundy, 1981; Vouloumanos and Werker, 2004), they soon undergo perceptual narrowing to the properties of their native language by their first birthday, and their perception of language continues to be honed by their home language experience (Werker and Tees, 1984; Kuhl, 2004; Werker and Curtin, 2005; Kuhl and Rivera-Gaxiola, 2008).[1] The attraction to language signals and the subsequent tuning to language-specific linguistic properties is observed not only in spoken languages but in signed languages as well (Baker et al., 2006; Krentz and Corina, 2008; Palmer et al., 2012). It is widely believed that this process is enabled by infants' selective attention to distinctive communicative signals and statistical patterns in their environments (Saffran et al., 1996). Understanding language development is well studied from an auditory-speech perspective (e.g., Jusczyk, 1997, 2016), but language is rarely singularly heard without looking at a speaker's face, talking mouth, and gesticulating body. Face-to-face communication is inherently multimodal. Infants and children need to learn what parts of their acoustic and visual worlds are linguistically relevant; this is a puzzle given that humans engage in constant vocal and body movements, some of which are gestures or signs used to communicate. Early perceptual attunement from this multimodal perspective is not well understood. In Experiment 1, we examined whether infants show selective visual attention (by means of differential gaze patterns) to different classes of body actions at two ages, 6 and 11 months and, in Experiment 2, we examined whether this sensitivity is shaped by the modality of language experience in young children between 2 and 8 years of age.

Findings from developmental studies indicate that infants can distinguish and derive meaning from classes of human body actions. Young infants aged from 5 to 9 months are sensitive to the goal-directed nature of manual reaching and grasping (Woodward, 1998; Woodward et al., 2001; Behne et al., 2005; Reid et al., 2007; Daum et al., 2009). They also have expectations about how the body and arms are supposed to move (Komori, 2006; Christie and Slaughter, 2010; Morita et al., 2012; Hannon et al., 2017). By 10–12 months, they can make sense of the intent of novel body action behaviors from video (Meltzoff, 1995, 1999; Wellman and Phillips, 2001; Csibra et al., 2003). They also make use of gaze direction, gestures, body posture, and emotional expressions to guide such intentional inferences (Tomasello, 1999; Baldwin, 2016). Although infants acquire the sense of body action perception in the first year of life, other recent studies suggest that infants struggle to make the leap to understand body actions as symbolic *representations* (Novack et al., 2018). This ability may require mastering certain language milestones and/or acquiring knowledge about how objects are used before understanding body actions as communicative gestures (Novack and Goldin-Meadow, 2017). For instance, toddlers around age 1–2 years imitate the goals of other person's actions and visually anticipate other's future actions (Hamlin et al., 2008; Cannon and Woodward, 2012), *but* when shown an instrumental body action (such as hammering with no object), and asked to pick one of the two objects, they pick the correct instrument no greater than chance (Namy, 2008; Novack et al., 2018). This ability to connect a symbolic gesture and its referent is not reliably in place until about 2 and 5 years of age (Namy, 2008; Goodrich and Hudson Kam, 2009; Dimitrova et al., 2017).

In other recent studies, infants' attention to talkers' faces is intricately linked to language developmental milestones and is modulated by language experience, such as bilingualism. Between 6 and 8 months, the infants attend to the talker's mouth; at 12 months, attention shifts to the eyes *unless* they view a silent talker of an unfamiliar language; then they continue to attend to the mouth (Lewkowicz and Hansen-Tift, 2012; Tenenbaum et al., 2013). The explanation offered for this shift is that infants look for articulatory cues (i.e., the mouth) at a time when they have not yet mastered speech production; after this developmental stage, they shift to focus on social body cues, i.e., the eyes (Lewkowicz and Hansen-Tift, 2012; Rutherford et al., 2015). It is to be noted that these studies typically show the head of a talker, without a stationary or gesticulating body. Nonetheless, these findings are critical because visual attention to the face in the first year of life has emerged as a meaningful predictor of later social and language developmental outcomes in toddlers and preschoolers (Morales et al., 1998; Brooks and Meltzoff, 2008; Young et al., 2009; Chawarska et al., 2013; Tenenbaum et al., 2014; Peltola et al., 2018; Morin-Lessard et al., 2019).

Together, this body of research on the development of visual attention patterns in infants supports a notion of developmental shifts in the sensitivity to, and understanding of, communicative human actions conveyed through speakers' bodies and faces. That is, once infants gain an understanding of the biomechanical constraints and basic functional properties of human actions, they shift to understand body actions as carriers of causal intention and meaning (Meltzoff, 1995, 1999; Wellman and Phillips, 2001). Infants' gaze patterns to faces demonstrate their understanding of the relationships between articulatory facial movements and speech while later index their awareness of a social-dyadic communication system in which the interlocutors' eyes hold informative clues. However, what happens when the primary mode of articulation is not the mouth but the *hands*, and how does experience with a visual language modality influence early understanding of body

1 Perceptual attunement has been used synonymously with "perceptual narrowing," wherein infants lose sensitivity for non-native contrasts whilst gaining sensitivity for native contrasts between 8 and 12 months (Tees and Werker, 1984; Kuhl et al., 1992); however, we use attunement to refer to when perceptual sensitivities qualitatively change, perhaps becoming more or less specific, to fit or attune to the input.

actions? We know little about the developmental changes that arise when human body actions are systematized as linguistic communicative signals, as in the case of naturally occurring signed languages. Contrasting signed-manual or spoken-oral modalities of language transmission can provide a critical test of current cognitive developmental theories. Two fundamental questions are addressed in the present study: *First*, do infants' visual attention reveal sensitivity to different classes of human actions (e.g., visual-manual language as compared to self-directed body actions and symbolic pantomime)? *Second*, does language experience as spoken or signed influence visual attention to body actions in young children?

Signed languages are structurally complex, naturally evolving communicative systems used by deaf people and acquired by hearing children of deaf adults (CODAs) as a first language with the same timeline as children learning a spoken language (Petitto and Marentette, 1991; Lillo-Martin, 1999; Rinaldi et al., 2014; Newport and Meier, 2017). Within the field, there is very good consensus that signed languages display core linguistic properties that are characteristic of those identified in spoken languages (Stokoe, 1960; Klima and Bellugi, 1979; Sandler and Lillo-Martin, 2006; and refer to Pfau et al., 2012 for a review). Moreover, there is substantial evidence that the cognitive processes involved in signed and spoken language are qualitatively similar, such as the mapping between perceptual forms (either visual or auditory) and stored lexical representations, the activation of phonological forms and lexical-semantic meaning, and the involvement of attention and memory processes engaged during the parsing and comprehension of linguistic forms. In addition, there is well-established evidence for commonalities in the core cortical and subcortical brain systems that mediate spoken and signed languages (Emmorey, 2001; Corina and Knapp, 2006; Corina and Blau, 2016; Corina and Lawyer, 2019). One difference from spoken language is the greater prevalence of signed lexical items whose forms are physically motivated through body actions, where the articulation of the form carries transparency about the form's meaning [e.g., DRINK in American Sign Language (ASL) is similar to how most would communicate the action of drinking through gesture; Ortega, 2017]. Indeed, there is convincing evidence that lexical signs evolved from earlier forms of symbolic manual gestures (Frishberg, 1975; Kegl et al., 1999; Morford and Kegl, 2000; Armstrong and Wilcox, 2003; Goldin-Meadow, 2005; Sandler et al., 2005; Senghas, 2005; Goldin-Meadow and Brentari, 2017). Although signs may have a gestural origin, they differ in systematic ways from pantomimic gestures. First, pantomimic body actions are holistic, with meaning derived from the whole, not parts (McNeill, 1992; Sandler and Lillo-Martin, 2006). They are less conventionalized and more idiosyncratic across individual productions (Wilcox and Occhino, 2016; Lepic and Occhino, 2018). In contrast, lexical signs are conventionalized forms with clear sub-lexical structure built from constrained (and language-specific) inventories of handshapes, orientations, places of articulation on the body, and movement trajectories (reviewed in Wilbur, 1979; Nespor and Sandler, 1999; Brentari et al., 2018). Differences in the features of any of these phonological units result in a different meaning for the sign providing evidence for the duality of patterning seen in the spoken language (Stokoe et al., 1976; MacSweeney et al., 2004). In sum, there are both similarities and differences between gestural body actions and lexical signs that might shape how infants and children perceive and learn them.

Prior studies have revealed that typically hearing non-sign-exposed 6-month-olds are sensitive to visual signed languages. For example, they show preferences for ASL over pantomimed actions (Krentz and Corina, 2008), a preference that is not observed in 10-month-olds. In addition, there is growing evidence for the perceptual narrowing of sensitivity to distinctive components of signed languages. Indeed, sign-naïve infants can categorically perceive a continuum of open-closed handshapes (Baker et al., 2006; Palmer et al., 2012). Infants also look longer at well-formed over ill-formed lexicalized fingerspelling (Stone et al., 2018). Six-month-olds can perceive syllabic reduplication common to linguistic signs, and their neural response differs from visual controls (Berent et al., 2021). Nine-month-old infants are sensitive to intonational phrase boundaries in child-directed-signing (Brentari et al., 2011). These sensitivities have been found to wane by 12 months of age in hearing infants not exposed to sign language (Baker et al., 2006; Krentz and Corina, 2008; Palmer et al., 2012; Stone et al., 2018, but cf. Brentari et al., 2011). While these studies demonstrate that sign-naïve infants show particular preferences for linguistic manual movements, we do not yet know how infants and children extract information from these body action displays to form these biases or whether the information they seek changes over time. In the present study, we use eye tracking methodology to address this gap.

In Experiment 1, we compared gaze patterns in hearing sign-naïve 6-month and 11-month-olds to assess whether they have selective attentional biases for different body action types. Specifically, we contrasted overt visual attention for linguistic body actions (series of lexical ASL signs produced without mouthing or facial expressions), intransitive self-directed body actions ("grooming," such as scratching face, brushing shoulder, and smoothing hair), and object-directed pantomime body action ("mimes," such as catching a ball, turning pages of a newspaper, and cracking an egg) created by a native signer. The inclusion of two types of non-linguistic actions (self-grooming and pantomimic) were included to examine whether the symbolic content of the actions might drive changes in eye-gaze behavior. While pantomimes are symbolic, the self-grooming actions lack this quality. The extent to which the participant groups differ in their visual attention across these body action types provides evidence that they are able to differentiate them. Specifically, if body action perception follows evidence of attunement (discussed above), then 6-month-olds, but not 11-month-olds, should show different gaze patterns for the body action types. Moreover, we reasoned the two regions, the face and the articulatory space where the hands produce language, might compete for infants' attention. On the one hand, infants might have a strong attentional bias for a signer's face because infants are known to be highly attracted to faces that provide emotional-social cues (Frank et al., 2009, 2014; Reynolds and Roth, 2018). Alternatively, infants might show a strong attentional bias to look at the articulatory space (in front of the torso) where the hands primarily fall.[2] This is expected because infants do have an attraction to look at perceptually salient moving objects over stationary ones (Slater et al., 1990; Arterberry and Bornstein, 2002). Also, as infants age, they demonstrate increasing interest in looking at hands and anticipate the motion of hands when agents perform actions on objects (Aslin, 2009; Slaughter and Heron-Delaney, 2011; Frank et al., 2012; Reddy et al., 2013).

In Experiment 2, we addressed our second question about whether linguistic experience influences visual attention patterns for different classes of human body action by contrasting native-signing CODAs vs. non-sign-exposed hearing children. As described above, native signers are exposed from birth to a formal visual-manual language that serves as their primary means of communication at home. They also might have extensive experience with pantomimic and gestural communication (Emmorey, 1999). As such, we hypothesized that experience with a visual language may shift visual attention patterns of native signers, making them different from non-signing children. Specifically, group differences would reflect CODAs' unique social and language knowledge, while non-signing children would be driven by perceptually salient attributes in the stimuli. This is the first study to address this topic in children. All methods were identical for both Experiment 1 (infants) and Experiment 2 (children).

## Experiment 1: Method

### Participants

A total of 46 hearing infants between 5 and 14 months of age were tested. Three participants did not complete testing, 2 were excluded because of poor calibration, and 2 did complete the testing, but were removed for insufficient data. All the remaining 39 infants included in the analysis completed the entire experiment (refer to **Table 1**). Two groups were tested, 22 6-month-olds (8 males/12 females; mean age = 6.04 mos) and 17 11-month-olds (9 males/8 females; mean age = 10.85 mos). All infants were from monolingual English-speaking homes, and, based on our selection criteria, had typical hearing and no sign language exposure. Race was reported as 67% White, 13% Hispanic, 8% Black, 8% Asian, and 5% mixed.

All participants were reported to be healthy and free from neurological impairments or other major disabilities. The Institutional Review Board at UCSD approved the experimental protocol, and written informed consent was obtained from the parents when they arrived at the lab. Testing was completed within a 30-minute visit to the lab before the COVID-19 Pandemic.

### Apparatus

Visual stimuli were presented on a Hewlett-Packard p1230 monitor (1440 × 1080 pixels; 75 Hz) controlled by a Dell Precision T5500 Workstation computer, using Tobii Studio 3.4.2 software. A Tobii 120X eye tracker is a free-standing device positioned in front of the participant, just under the monitor, and was used to track the participant's near-infrared reflectance of both eyes, with an average gaze position accuracy of 0.57° of visual angle. The tracker provided *x-y* coordinates for each eye that corresponded to the observer's gaze point on the monitor, during stimulus presentation, recorded at a sampling rate of 120 hertz. From these data, we averaged across the eyes to provide binocular eye gaze position in *x-y* space, every 8.33 ms.

### Materials

The stimuli consisted of alternating video sequences of three body action types: body grooming (e.g., rubbing hands or fixing hair), pantomimed actions (e.g., clicking a mouse or picking an apple from a tree), and ASL signs (e.g., HOT, FREE, and ASK), produced as citation forms by the same female native signer (refer to **Supplementary material** for a list of all 56 items). The signing model was given an English glossary of each word or description of the action and made her own natural articulation for each. The signer was instructed to produce all actions and signs with a neutral facial expression. For each token, the signer started with her hands folded in front of her lower torso, produced the token, returned her hands to the same position, paused for 1s, and then produced the next item.

We balanced the number of sign and body action tokens that were executed with one or two hands, had a clear handshape change, and had clear path movements. For each of the three body action types, exactly 50% of tokens had handshape change, and 50% did not. The number of sign and body action

2 There are certainly perceptual pressures to look directly at the hands, i.e., "articulators," if one wants to perceive them clearly. First, the majority of signs have a specific location in front of the torso below the mouth (Sehyr et al., 2021). During signed conversations viewed a few feet away, the interlocuter's hands primarily fall, on average, 6.5°, and as far as 16°, below the interlocuter's eyes (Bosworth et al., 2019). Therefore, the hands, when fixating on the face, are seen with a spatial resolution of ∼25% of that seen with foveal vision (Henderson, 2003).

TABLE 1 Demographics of study participants.

| Age group | N | Male/female | Mean age in months (SE) | Median | Range |
|---|---|---|---|---|---|
| Six-month-olds | 22 | 10/12 | 6.04 (0.12) | 6.05 | 5.0–7.0 |
| Eleven-month-olds | 17 | 9/8 | 10.85 (0.33) | 10.50 | 7.8–14.0 |
| **Language group** | ***N*** | **Male/female** | **Mean age in years (SE)** | **Median** | **Range** |
| Non-signing children | 18 | 8/10 | 4.77 (0.37) | 4.67 | 2.90–8.02 |
| Native signing children | 13 | 7/6 | 5.70 (0.68) | 5.93 | 2.08–8.32 |

Age for infants presented in months and for children in years.

tokens with a clear movement path vs. no movement path was equivalent.[3] The number of tokens with two articulating hands were 71, 71, and 57% for Signs, Mimes and Grooming, respectively, with the rest one-handed. The total video duration of each of the Sign, Mime, and Grooming conditions were 39.14, 44.40, and 58.45 s, respectively.

Viewed from a distance of 65 cm, the height of the signing model was 18.3°, shoulder width was 7.8° of visual angle, and the distance between the center of her eyes was 2°. Videos of the signer were presented upon a full-monitor screen, 1,440 × 1,080 pixels, upon a white background.

## Procedure

The infant sat on a booster seat on the parent's lap. The parent wore glasses with opaque filters and was discouraged from interacting with their child unless necessary. The experimenter sat behind a curtain, unseen by the participant.

Participants were calibrated using a 5-point calibration procedure, using a small spinning pinwheel circle presented for 1–3 s in each of 5 locations (see **Figure 1**). Once the participant was successfully calibrated, we recorded gaze data for these circle targets, which was used off-line to verify calibration accuracy. Visual inspection showed no discernable drifts or significant changes in calibration for any participant.

Refer to **Figure 1** for the timeline of the experiment. The total experiment lasted approximately 7 min. The 8 trials (each with 7 tokens) were interspersed with a still picture of a dog in the center of the monitor. When the participant's eye gaze was centered on the dog, the experimenter initiated the test trial. Participants saw each Body Action Type with the order of condition counterbalanced. Counterbalanced group assignment alternated for each consecutive subject. Data analysis was done with counterbalanced groups collapsed in an effort to control for order effects.

## Data analysis

### Raw gaze data

Raw eye gaze data in *x*-*y* form, indicating horizontal (*x*) and vertical (*y*) positions in 2-D space, were obtained for each eye, and averaged across both eyes. The four trials for each condition were combined for all analyses to protect against order effects. To examine whether the groups demonstrated different *overall looking times* for the various body action types, an ANOVA was conducted with between-subjects factor Age Group (6-, 11-months) and repeated-subjects factor Body Action Type (Grooming, Mimes, and Signs).

### Area of interest analyses

To examine where participants look, we created a grid of Areas of Interest (AOI) boxes superimposed upon the image of the signer (**Figure 2**). AOIs were drawn using Tobii Studio Pro software. The grid was dynamically "locked" onto the signer's body such that when she moved (albeit slightly), the grid moved with her. In this way, the boxes always were linked anatomically to a region of her body (i.e., the "mouth" box is always centered to her mouth). Gaze samples (e.g., eye position every 8.33 ms) were summed as hits for each AOI box. For purposes of illustration, we present summary gaze patterns for all AOIs in the entire grid in **Figures 3** and **4**. Most of the gaze data fell on the signer's body, with very few gaze points outside the signer's body region. As such, we concentrated our analyses on the face (later divided into mouth and eyes) and the torso, which is the primary "articulator" space in front of the singer where the articulators fall the majority of the time.[4]

3 Recall that all signs and body actions (Grooming and Mimes) were executed by the native signer model starting and ending with her hands at "resting" at her sides. These movements are typically considered to be "transitional" movements. The designation of path and no-path movement refers to the articulation of the sign and body action tokens that were executed in between this transitional movement envelope. Movement paths were considered to be those sign or body action tokens with a clear ballistic motion of the arms and hands, while no-movement path designated forms that consisted of a relatively fixed contact point on the body.

4 Specifically, we counted frames when the hands were in the torso space for our stimuli which was about 75% of the time. This estimate agrees with what is generally known about signing space (Bosworth et al., 2019; Sehyr et al., 2021). Even for signs that have contact with the head, which comprise about 20% of lexical signs in ASL, the hands must go through articulatory space.

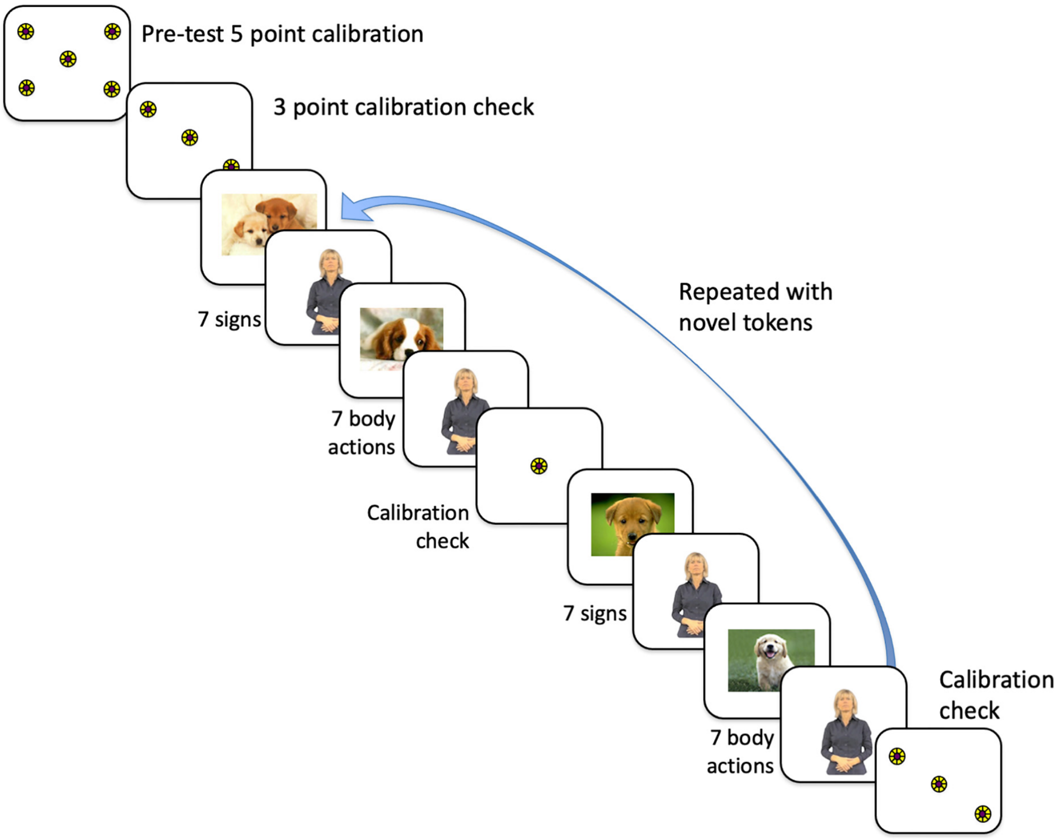


FIGURE 1
Order of presentation of stimuli to participants, which first commenced with a 5-point calibration routine, then a 3-point calibration check. We proceeded with the experiment only if that calibration was within the tolerance limits (with gaze falling on each circle). The experimental conditions consisted of alternating trials of 7 signs and trials of 7 body actions, either grooming or pantomimes, with each trial presented twice. Participants never saw the same token twice. For the data analysis, the trials were collapsed to eliminate order effects.

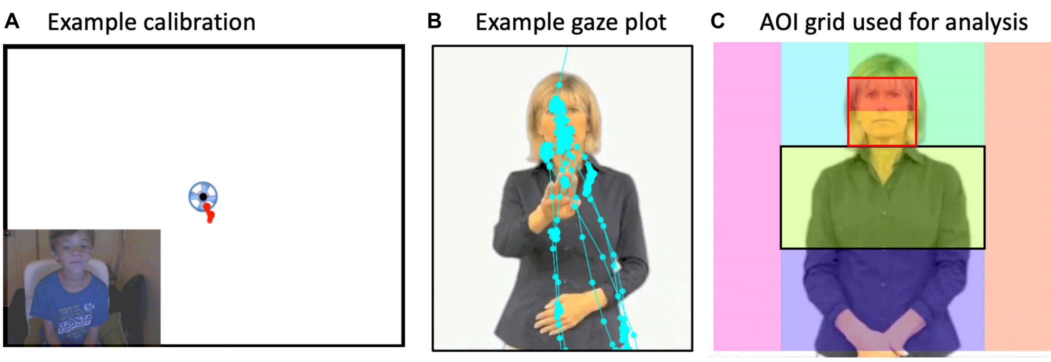


FIGURE 2
**(A)** Example calibration from a child. If the gaze "hit" the spinning circle at each beginning, middle, and at the end of the experiment, then data were included in analyses. **(B)** Example "raw" gaze plot showing fixation points from one trial and one participant. **(C)** The signer was superimposed with an Areas of Interest (AOI) grid. Gaze points in each box were summed to equal the total time spent gazing at each AOI box. Then, for main analyses, percent looking in each AOI box was computed as total looking time spent in the AOI divided by the total amount of time spent looking at the whole image (i.e., all boxes). Gaze data primarily hit the midline column of AOIs and rarely off the signer's body. Main analyses were conducted on face preference index (FPI) values. FPIs were calculated for each participant as the Face AOI (outlined in *red*) divided by the Face and "Torso" AOIs (outlined in *black*).

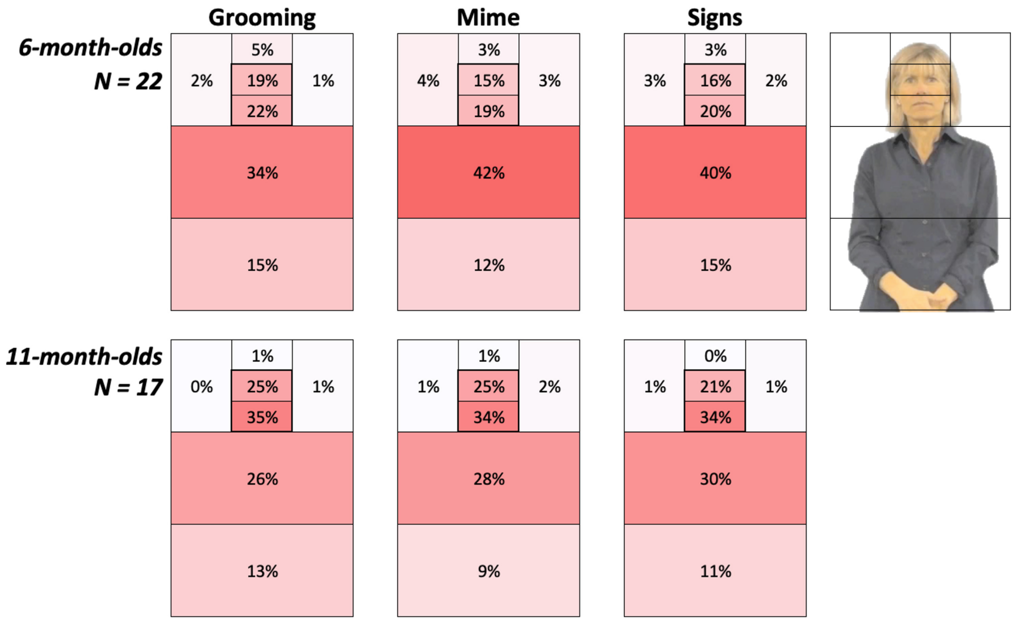


FIGURE 3
Heat Grids for each age group and Body Action type conditions. These results show the average percent looking time for each AOI, separately for 6-month-olds (*top*) and 11-month-olds (*bottom*). Color scaling per cell refers to a gradient from the highest (red) to the lowest (white) percent looking values. The outline in the upper right corner represents the AOI locations on the signer. Each grid, including the Left and Right side of AOIs, sums to 100%. As discussed in the Results, 6-month-olds were more drawn to the articulatory space while 11-month-old infants spent 19–25% more time attending to the face.

## Face preference index values

We explored statistical differences in where participants look at the signer by computing, for each participant, a *face preference index* (FPI) with percent looking time values, as (Face − Torso)/(Face + Torso); refer to Figure 2. This was motivated by a practical desire to reduce the number of comparisons and to test our primary hypotheses about relative visual attention (by means of gaze) to the *face vs. articulatory space* (torso). The face and the moving hands are both highly salient cues that may compete for participants' attention. The hands, which we refer to globally as the "articulators," primarily fall in the torso region, commonly called "signing space." Positive values reflect greater looking at the face than the region below the face. With these FPI values, we could test the prediction that participants might be primarily drawn to either the signer's face or the signer's moving hands (or both equally so). Further, we can test predictions about whether the participants look at different parts of the signer for the three different body action types. If they do, this is evidence that they are sensitive to the differences between these stimulus types.

Face preference index data were analyzed first with a mixed 2 × 3 ANOVA, with between-subjects factor Age Group (6- vs. 11-month-olds) × repeated-subjects factor Body Action Type (Grooming, Mimes, and Signs). Planned comparisons for visual attention to Grooming, Mimes, and Signs were conducted using a one-way ANOVA with each participant group.

Levene's tests of homogeneity of variances were found to be equal, $p > 0.24$. We observed no visible order effects and confirmed no significant differences between Video Groups 1 and 2 (used to counterbalance the presentation of tokens and condition order), nor were there interactions of any factors with Video Group.

# Experiment 1: Results

## Overall visual attention to body action types

In terms of the total number of gaze samples provided, 6- and 11-month-old infant groups provided, on average, 75.04 (SE = 5.85) s and 86.16 (SE = 4.42) s of the total gaze data. There was no difference between the two age groups, $F(1,37) = 2.08$, $p = 0.16$, $\eta^2 = 0.05$.

Infants' percent looking averages for each condition are presented in Table 2. First, we checked whether the body action types varied in capturing the *overall interest*, irrespective of where one looks (our main interest). To this end, we conducted a 2 × 3 ANOVA with between-subjects factor Age Group (6, 11-month-olds) and repeated-subjects factor Body Action Type (Grooming, Mime, and Signs) with total percent looking at each stimulus condition, collapsed across all trials and AOIs. There

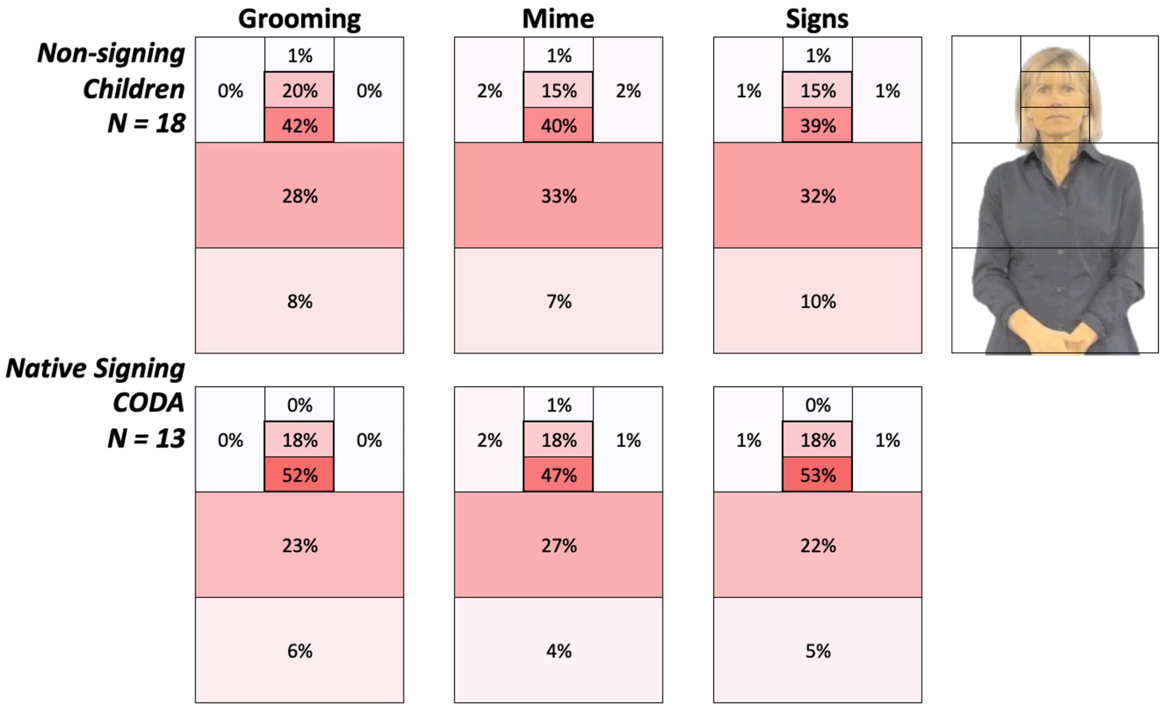


FIGURE 4
Heat grids for each language group and body action type conditions. These results show the average percent looking time for each AOI for non-signing (*top*) and native signing children (*bottom*). Color scaling per cell refers to a gradient from the highest (red) to the lowest (white) percent looking values. The most notable overall difference between groups was the greater attention to the face in native signing children, especially for signs, than the non-signing children. Conversely, this also reflects non-signing children's higher percentage looking at the articulatory space.

was no main effect of Age Group, $F(1,37) = 2.04$; $p = 0.16$; $\eta^2 = 0.05$ or interaction with this factor, $F(2,74) = 0.36$; $p = 0.70$, $\eta^2 = 0.01$. This means that the two age groups did not differ in the overall attentiveness, cooperation, or interest across the three body action types.

## Visual attention to face vs. articulatory space

Figure 3 provides color-coded illustrations of the average percent looking times for each AOI, with each participant's AOI grid summing to 100%. Darker regions indicate AOIs that contained the greatest number of gaze points and attracted the most attention. These figures show 6-month-olds were more drawn to the articulatory space, while 11-month-old infants spent more time attending to the face.

In the main analysis, we asked where participants spend their time looking, which we divided into two central regions, the *Face* and *Torso* regions. As discussed earlier, we reasoned that these two regions might compete for infants' attention, and this might depend on body action types. We statistically analyzed the distribution of attention and whether this depended on body action types using FPI values. Participants might have a positive FPI value because infants are known to be highly attracted to faces, especially of talkers and signers. Conversely, if infants are drawn to attend to perceptually salient parts of the image, such as the moving hands, they would show a negative FPI value.[5]

We conducted an ANOVA on FPI values from each participant with two factors, between-subjects factor Age Group (6-, 11-month-olds) and repeated-subjects factor Body Action Type (Grooming, Mimes, and Signs). Significant main effects were found for both Age Group, $F(1,36) = 9.01$; $p = 0.005$; $\eta^2 = 0.20$, and Body Action Type, $F(2,72) = 5.44$; $p = 0.006$; $\eta^2 = 0.13$. The Age Group and Body Action Type interaction showed a non-significant trend, $F(2,72) = 2.23$; $p = 0.11$; $\eta^2 = 0.06$. As shown in Figure 5, this lack of interaction was driven by *11-month-olds* showing uniformly highly positive FPI

5 One could ask if the hands fall to the sides of the signer and whether participants looked at them. The hands did fall in these regions about 3% of the time (based on frame count). There is an intriguing but small, right-side looking bias for both infant age groups and for all body action types. The combined Left and Right side AOI average looking values (not shown in figures) are as follows: *6-month-olds:* Grooming: 1.21%; Mimes: 2.25%; Signs: 0.49%; *11-month-olds:* Grooming: 0.24%; Mimes: 0.48%; Signs: 0.55%. The Left and Right side AOI average looking values for the young children in Experiment 2 were less than 1%.

TABLE 2 Percent gaze recorded for each stimulus condition, normalized by video duration.

| Participant group | Grooming | Mime | ASL signs |
|---|---|---|---|
| 6-month-olds (*N* = 22) | 45.91% (5.00) | 56.64% (4.34) | 53.80% (3.32) |
| 11-month-olds (*N* = 17) | 56.69% (5.68) | 62.99% (4.95) | 60.08% (3.77) |
| Non-signing children (*N* = 18) | 76.52% (6.78) | 73.29% (4.08) | 68.27% (4.78) |
| Native signing children (*N* = 13) | 72.34% (6.12) | 65.05% (9.67) | 73.07% (7.62) |

Averages and standard errors of the mean are presented.

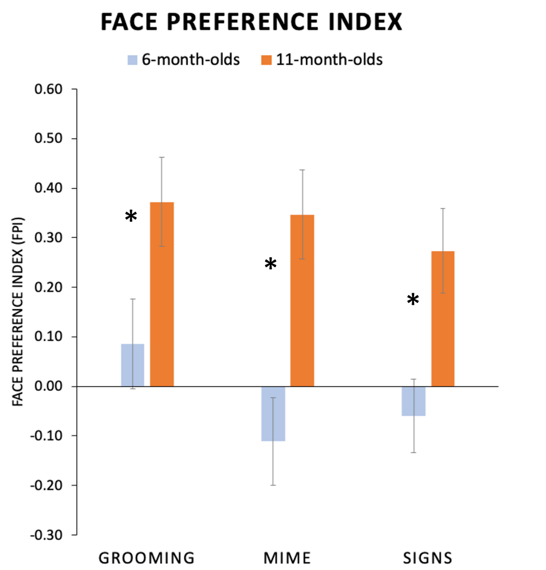


FIGURE 5
Average face preference index (FPI) values for each age group and condition. FPI values are plotted on the *y*-axis, with positive values indicating greater attention devoted to the face than the torso area and negative values indicating the opposite preference. Six-month-old infants attended to the face for Grooming body actions and to the torso region for both Mimes and Signs. Eleven-month-old infants showed an evenly high face preferences for all conditions. (Standard error bars plotted*, $p < 0.05$).

values (i.e., a robust face attentional bias) for all body action types. Refer to Table 3 for mean FPI values.

Although the overall interaction did not reach significance, based upon our hypotheses about attunement discussed above, we explored this trend by conducting a one-way ANOVA with repeated-subjects factor Body Action Type (Grooming, Mimes, and Signs) separately for each age group as a test of the specific prediction that younger infants would have different visual attention patterns for body action types. Indeed, as predicted, the *6-month-olds* revealed a significant main effect of Body Action Type, $F(2,40) = 6.60$; $p = 0.003$; $\eta^2 = 0.25$, while *11-month-olds* did not, $F(2,32) = 1.42$; $p = 0.26$, $\eta^2 = 0.08$. Specifically, younger infants showed a significantly higher face preference for *Grooming* compared to *Mimes* (Mean Difference = 0.20, $p = 0.004$, 95% CI [0.07, 0.32]) and *Signs* (Mean Difference = 0.15, $p = 0.02$, 95% CI [0.03, 0.27]). Mean FPIs for Mimes vs. Signs were not significantly different (Mean Difference = −0.05, $p = 0.38$; CI [-0.15, 0.06]). None of these contrasts in the *11-month-olds* were significant, with all *p*-values > 0.20.

## Attention to the eyes, mouth, and articulatory space

We followed the main analysis with an exploration of visual attention (in terms of percent looking) to the eyes vs. mouth (which together make up the face in the FPI analyses) and whether this pattern was related to age. Specifically, we examined the correlation of age with percent looking time for the key AOIs analyzed above, the eyes, mouth, and torso.

In all infants tested, who ranged in age from 5.0 to 14.0 months, attention to the *mouth* increased with age ($r = 0.49$; $p = 0.001$), matched with a corresponding decrease in attention to the *torso* ($r = -0.33$; $p = 0.04$), while looking at the *eyes* remained stable with age ($r = 0.15$; $p = 0.34$). Refer to the mean values in Table 4.

# Experiment 1: Discussion

Results showed that hearing sign-naïve 6-month-olds were drawn more to the articulatory space, while 11-month-old infants spent more time attending to the face. Moreover, 6-month-old infants showed differential visual attention for Grooming compared to Mimes and Signs, while 11-month-olds showed uniformly robust face attentional bias for all body action types. This pattern suggests an early perceptual sensitivity to classes of body actions that wanes around one year of age in the absence of signed language exposure, also recently reported for the perception of handshapes (Baker et al., 2006; Palmer et al., 2012; Stone et al., 2018). Exploratory analyses indicated that across the ages of 5–14 months, attention to the mouth increased, mirrored with a decrease in attention to the articulatory space where the hands primarily fall, while looking at the eyes remained stable with age.

We now turn to Experiment 2 to address the question about whether linguistic experience influences gaze preference

TABLE 3 Mean face preference index (FPI) values for each group and condition.

| Participant group | Grooming | Mime | ASL signs |
|---|---|---|---|
| 6-month-olds ($N$ = 22) | 0.086 (0.09) | −0.108 (0.09) | −0.062 (0.08) |
| 11-month-olds ($N$ = 17) | 0.372 (0.10) | 0.347 (0.10) | 0.277 (0.09) |
| Non-signing children ($N$ = 18) | 0.379 (0.07) | 0.22 (0.08) | 0.241 (0.08) |
| Native signing children ($N$ = 13) | 0.478 (0.08) | 0.40 (0.09) | 0.513 (0.09) |

Standard errors of the mean are presented.

TABLE 4 Mean percentage looking values for each group, collapsed across body action type.

| Participant group | Eyes | Mouth | Torso (Articulatory space) |
|---|---|---|---|
| 6-month-olds ($N$ = 22) | 16.20% (2.81) | 20.49% (2.30) | 38.95% (3.31) |
| 11-month-olds ($N$ = 17) | 23.74% (5.07) | 34.21% (3.53) | 27.91% (3.32) |
| Non-signing Children ($N$ = 18) | 16.97% (2.94) | 40.29% (4.05) | 30.75% (2.97) |
| Native Signing Children ($N$ = 13) | 17.71% (2.85) | 51.14% (2.71) | 24.19% (2.59) |

Standard errors of the mean are presented.

for different classes of human body action by contrasting native-signing CODAs vs. non-sign-exposed hearing children. Native signers are exposed from birth to a formal visual-manual language that serves as their primary means of communication at home. We hypothesized that experience with a visual language may shift visual attention patterns for native signers, making them different from non-signing children. All methods were identical for both Experiment 1 (infants) and Experiment 2 (children).

# Experiment 2

All stimuli and procedures are identical to Experiment 1.

## Participants

A total of 35 hearing children were tested. Two participants' data failed to be recorded due to experimenter error, and an additional 2 were removed for poor calibration. All the remaining 31 children between 2 and 8 years of age (mean age of 5.16 years) included in the analysis completed the entire experiment (refer to **Table 1**). One group of 18 children (8 males/10 females) were monolingual English speaking at home and, based on our selection criteria, had no sign language exposure. The other group consisted of 13 "CODAs"; (7 males/6 females) whose deaf parents' primary language was ASL. CODAs are typically considered *native signers*. Parents self-reported that they used ASL as their primary language and used it at least 80% of the time. Prior to testing, all deaf parents completed a self-rated proficiency test, taken from Bosworth et al. (2020). All deaf parents gave themselves the maximum rating of 5. We did not assess the language fluency in children. All participants were reported to be healthy and free from neurological impairments or other major disabilities.

The mean ages of the non-signing and native signing groups were 4.77 and 5.70 years, respectively, and did not differ significantly in age, $F(1,29) = 2.020$; $p = 0.166$; $\eta^2 = 0.065$. Race was reported as 44% White, 15% Hispanic, 18% Black, 0% Asian, 3% mixed, and 20% not reported.

The children completed the Matrices subtest of the Kaufman Brief Intelligence Test, 2nd Edition (K-BIT2; Kaufman and Kaufman, 2004), which is an index of non-verbal intelligence. The two groups of non-signing and native signing children did not differ significantly in this test, $p > 0.20$.

The Institutional Review Board at UCSD approved the experimental protocol, and written informed consent was obtained from the parents when they arrived at the lab. Testing was completed within a 30-min visit to the lab before the COVID-19 Pandemic.

## Procedure

The children sat alone on a chair. The tester used spoken English with non-signing children and both English and ASL with the native signing children. Children were instructed to simply watch the video which they might find enjoyable. All other procedures were identical to Experiment 1.

## Data analysis

Raw eye gaze data were processed as described above in Experiment 1. An ANOVA was conducted with between-subjects factor Language Group (Non-signing and Signing) and repeated-subjects factor Body Action Type (Grooming, Mimes, and Signs). To examine where participants look, we created a grid of AOI boxes superimposed upon the image of the signer (refer to Figure 2). For purposes of illustration, we present summary gaze patterns for all AOIs in the entire grid in Figure 4. Most of the gaze data fell on the signer's body, with very few gaze points outside the signer's body region. As with Experiment 1, we concentrated our analyses on the face (later divided into mouth and eyes) and the torso, which is the primary "articulator" space in front of the singer where the articulators fall the majority of the time.

*FPI Values.* We explored statistical differences in where participants look on the signer by computing, for each participant, an FPI with percent looking time values, as (Face – Torso)/(Face + Torso). With these FPI values, we tested the prediction that language groups differ in where their attention is drawn, either the signer's face or the signer's moving hands (or both equally so). Further, we tested predictions about whether the participants look at different parts of the signer for the three different body action types.

Face preference index data were analyzed first with a mixed 2 × 3 ANOVA, with between-subjects factor Language Group (Non-signing, Signing) × repeated-subjects factor Body Action Type (Grooming, Mimes, and Signs). Planned comparisons for visual attention to Grooming, Mimes, and Signs were conducted using a one-way ANOVA with each participant group.

Levene's tests of homogeneity of variances were found to be equal, $p > 0.24$. We observed no visible order effects and confirmed no significant differences between Video Groups 1 and 2 (used to counterbalance the presentation of tokens and condition order), nor were there interactions of any factors with the Video Group.

## Experiment 2: Results

### Overall visual attention to body action types

Non-signing and native signing children provided, on average, 104.01 (SE = 6.20) s and 101.76 (SE = 10.77) s of total gaze data, respectively. There was no difference between the two Language Groups in the total amount of gaze data provided, $F(1,29) = 0.04$; $p = 0.85$; $\eta^2 = 0.001$.

Using total percentage looking at the stimuli, ANOVA results showed no main effect of Language Group, $F(1,29) = 0.097$; $p = 0.76$, $\eta^2 = 0.76$ or main effect of Body Action Type, $F(2,58) = 1.07$; $p = 0.35$, $\eta^2 = 0.036$, and no higher order interaction, $F(2,58) = 1.63$; $p = 0.21$, $\eta^2 = 0.05$. As such, there were no differences in the overall interest for the stimuli between the two participant groups or for the body action types (refer to Table 2). Both groups were equally interested and cooperative in viewing the stimuli. Even if they do not know ASL, they seemed to have high interest in watching it.

### Face preference index results

Figure 4 provides color-coded illustrations of the average percent looking times for each AOI, with each participant's AOI grid summing to 100%. Darker regions indicate AOIs that contained the greatest number of gaze points and attracted the most attention. The most notable overall difference between the groups was greater attention to the face in native signing children, especially for signs, than non-signing children. Conversely, this also reflects non-signing children's higher percentage looking at the articulatory space.

To examine the effects of ASL exposure on gaze patterns, we conducted a repeated measures ANOVA with between-group factor Language Group (Non-signing, Signing) and within-subject factor Body Action type (Grooming, Mimes, and Signs) using FPI values as the dependent measure. We first included age as a covariate, as age was neither significant, $F(1,26) = 0.798$, $p = 0.38$, $\eta^2 = 0.03$, nor did it interact with any factors, we dropped this factor. A significant main effect of Body Action Type, $F(2,54) = 3.72$; $p = 0.03$; $\eta^2 = 0.12$, and a marginal trend for the factor Language Group, $F(1,27) = 3.12$; $p = 0.08$; $\eta^2 = 0.10$, were found. There was no interaction between Body Action Type and Language Group, $F(2,54) = 1.96$; $p = 0.15$; $\eta^2 = 0.07$. Refer to Table 3 for mean FPI values.

Average FPI values are presented in Figure 6, separately for each participant group and for the three Body Action Type conditions. As shown in Figure 6, all child participants had positive FPI (i.e., a face preference) values for all body action types. We predicted that the native signing children would have a different gaze pattern than the non-signing children, and perhaps this would be different for the body action types. Indeed, native signing children had a significantly higher mean FPI than non-signing children did for *Signs*, (Mean Difference = 0.26, $p = 0.02$; 95% CI [0.04, 0.48]), and there were no group differences for *Grooming*, $p = 0.36$, or *Mimes*, $p = 0.15$.

### Attention to the eyes, mouth, and articulatory space

We followed the main analysis with an exploration of visual attention (in terms of percent looking) to the eyes vs. mouth (which together make up the face in the FPI analyses) and whether this pattern was related to age. Specifically, we examined the correlation of age with percent looking time for the key AOIs analyzed above, the eyes, mouth, and torso.

In the children tested, who ranged from 2 to 8 years of age, there were no significant correlations with age (all $p$-values > 0.20). As shown in Figure 4, native signing children spent much more time attending to the *mouth*, compared to the non-signing children (51.14% vs. 40.29%, $p = 0.03$) and less attention to the *torso* region (24.20 vs. 30.75%, $p = 0.11$), while

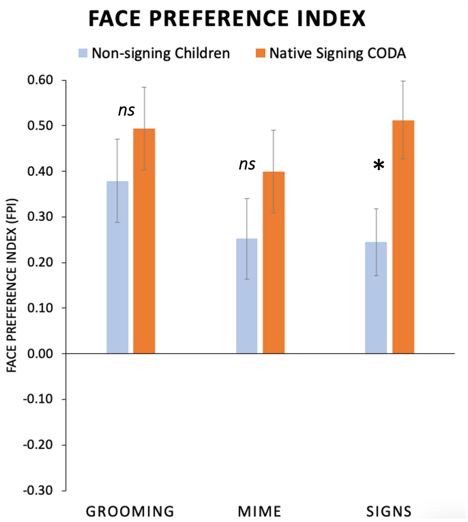


FIGURE 6
Average face preference index (FPI) values for non-signing and signing young children at the mean age of 5 years. Positive FPI values indicate greater attention devoted to the face than the torso area and negative values indicate the opposite preference. All participants had a high positive FPI. No group differences were seen for Grooming or Mime actions. For Signs, native signing children had a significantly greater FPI than the non-signing children. (Standard error bars plotted*, $p < 0.05$). ns, not significant.

both groups looked at the *eyes* the same amount of time (17.71 vs. 16.97%, $p = 0.86$). Refer to the mean values in Table 4.

## Experiment 2: Discussion

We predicted that the native signing children would have a different gaze pattern than the non-signing children, and perhaps this would be different for the body action types. Indeed, across all body action types, native signing children had a significantly higher mean face attention than the non-signing children did. This group difference was also significant for signs, while there were no group differences for the two non-linguistic body actions, grooming or mimes. Exploratory analyses indicated that native signing children spent much more time attending to the mouth and less time looking at the articulatory space, compared to the non-signing children, while both groups looked at the eyes in the same amount of time.

## General discussion

The present study tested whether young pre-linguistic infants have differential visual attention patterns for linguistic and non-linguistic body action types and whether this was modulated by age. In older children, we then examined whether a child's home language as visual-signed vs. spoken-auditory changes their visual attention for these forms. We contrasted gaze patterns for three classes of human actions presented as video sequences of ASL signs, self-oriented manual body actions (grooming, e.g., scratch neck and rub shoulder), and object-oriented pantomimes (mimes, e.g., tie a ribbon and turn a newspaper). We reasoned that if where one looks (i.e., overt visual attention) differs across these body action types, then this provides evidence that the infants and children can perceptually discriminate between them. An important strength of the current study is all stimuli were produced naturally, yet with necessary controls for perceptual matching, such as the similar use of articulatory space, use of two vs. one hand, and without mouthing, facial expression, or narrative prosody. This is important because narrative prosody is perceptually different in many ways from other body actions, which would make it difficult to contrast perception across body action types.

We found that 6-month-old infants showed greater attention to the articulatory space of a signer producing signs and mimes but more face-focused attention for grooming actions. This contrasts with the 11-month-olds who showed a uniformly robust attentional bias for the face, with no difference in the gaze behavior for linguistic vs. non-linguistic body action types. Native signing children exposed to a visual language at home had a significantly greater face attentional bias than non-signing children for ASL signs, but not for grooming and mimes. Together, these findings suggest the following important interpretations: young sign-naïve infants between 5- and 7-months of age can discriminate between visual linguistic and non-linguistic body types. This pattern of body action sensitivity diminishes between 8 and 14 months of age, presumably because they are not exposed to a visual-manual language, suggesting that the well-known attunement phenomenon is modality-general. Results from children between the ages of 2 and 8 years suggest that the modality of language experience in the home alters visual attention for visual-manual linguistic body actions. We address each potential interpretation in turn below.

Our results suggest that young sign-naïve infants, with minimal world experience, can discriminate linguistic signs from self-directed manual grooming body actions. This finding extends the well-known early hypersensitivity to acoustic and visual contrasts for unfamiliar language input and those within their home environment (reviewed in Kuhl, 2004; Vouloumanos and Werker, 2004). For example, young infants prefer native speech over non-speech prosody (Mehler et al., 1988) and signed stimuli over non-sign manual movements(e.g., Krentz and Corina, 2008). Infants at this age are sensitive to well-formed specific handshape and movement paths that adhere to linguistic rules in signed contrasts presented on the hands (Baker et al., 2006; Brentari, 2010; Palmer et al., 2010; Stone et al., 2018; Berent et al., 2021). These findings suggest that early perceptual sensitivity is *amodal*, such that infants are able to pick up on potentially relevant linguistic contrasts in either auditory or visual modalities. This sensitivity is precocious and supports later acquisition of words, concepts, and the relations between them (Yeung and Werker, 2009; Perszyk and Waxman, 2018). This early amodal sensitivity lays the foundation for the identical maturational patterns and timetable of the stages of language learning seen in both speaking and signing children (Bellugi and Klima, 1982; Newport and Meier, 1985; Petitto and Marentette, 1991; Lillo-Martin, 1999; Meier, 2002; Mayberry and Squires, 2006; Pichler et al., 2018).

While infants differentiated signs from grooming, they did not show differential visual attention to signs and mimes (refer to **Figure 5**). How did our stimuli differ in a way that infants could potentially identify grooming as perceptually distinctive from mimes and signs? First, we have a sense of what is *not* driving this effect from our description of the stimuli (described in **Supplementary material**). All body action types were closely matched in overall signing space, use of one vs. two hands, and whether the hands changed shape (including opening and closing). Also, all stimuli had no mouthing, body sway, or facial expression, so those attributes are unlikely to be driving infants' attentional differences in the present study. What differed between grooming vs. signs and mimes is likely the variation and complexity of handshapes. For instance, the mime stimuli employed more handling-like handshapes and more crisp handshapes, while grooming had few handlings and more lax handshapes. Another important difference is the role of the "self," the grooming actions involve the hands largely directed to the self, intentionally performing an act on or to the body, while the mimes and signs mostly are movements away from the signer and are executed for the sake of perception to "others." The ASL has many depicted actions that are very "mime-like" (Dudis, 2004), so having an ASL native signer execute the pantomimes might have influenced the execution of these forms to be more "sign-like" or communicative.

Another possible explanation for why infants did not differentiate mimes from signs, but did from grooming, is that perhaps more experience is needed to understand handling objects depicted in mimes.[6] Although infants acquire body action perception sense in the first year of life, studies suggest that infants do not understand body action as symbolic representation until after the first year of life (Novack et al., 2018). Around 10–12 months, but not before, infants can recognize the intentionality of body action behaviors on video and infer intention from gestures and body posture (Meltzoff, 1995, 1999; Tomasello, 1999; Wellman and Phillips, 2001; Phillips and Wellman, 2005; Baldwin, 2016). This ability to understand *instrumental* object-directed body actions may require mastering certain language milestones and/or acquiring knowledge about how objects are used before understanding body actions as communicative gestures (see Namy, 2008; Novack and Goldin-Meadow, 2017; Novack et al., 2018).

Our results from the older infants showing no differentiation in their visual attention patterns across body action types support the well-documented attunement that starts around eight months of age. This phenomenon has also been observed in an initial global preference for foreign speech that hones into a preference for native language prosody (Mehler et al., 1988; Nazzi et al., 1998, 2000). Our findings also contribute to the recent growing evidence that this phenomenon applies to *visual* modality as well. In these studies, sign-naïve 10- to 12-month-olds did not show a visual sign language preference (Krentz and Corina, 2008) or for either well-formed or ill-formed fingerspelling (Stone et al., 2018) that 6-month-olds did. Also, sensitivity to signed contrasts diminishes by 14 months of age without signed exposure (Baker et al., 2006; Palmer et al., 2012). Together, these findings suggest that young infants are sensitive to visual language, but without sign language exposure, the visual-manual modality is no longer a linguistic domain for them, as their attention, interest, and sensitivity hone to their native spoken language. Although we do not know what would happen with native signing 12-month-olds who hone in preference to their native sign language, recent studies suggest that native signing infants have mature visual attention patterns for social and linguistic signals in place by one year of age (Brooks et al., 2020; Bosworth and Stone, 2021).

Linguistic experience shapes visual attention to body action types, as seen by the present results comparing native signing children raised with ASL with monolingual English-speaking children. As shown in **Figure 6**, native signing children have significantly higher face-focus than non-signing children for signs, and there were no group differences for grooming or mimes. Examination of **Figure 4** shows that both groups look at the eyes for about the same amount of time while signing children spend much more time on the mouth region. Other evidence using displays of silent talking speakers also shows that visual attention to the face is shaped by bilingualism (Weikum et al., 2007; Pons et al., 2015; Mercure et al., 2018, 2019; Birules et al., 2019). The signing children's high attention to the face is very similar to that seen in native deaf adult signers in a companion study (Bosworth et al., 2020). In that study, adult signers who learned ASL in early childhood had the same robust face-focused attention when watching signed narratives, while adult novice signers' gaze was variable, especially for low-intelligibility stimuli. The fact that signers rarely foveate to the articulatory space (in front of the torso) means that the details of the hands primarily fall in the peripheral lower vision. This may explain why native signers develop an efficient perceptual "span" that becomes entrained with sign language exposure and leads to heightened visual sensitivity for the articulatory space (Caselli et al., 2022). Indeed, face processing and perception of the inferior visual field have been shown to be enhanced in the

6 In this line of reasoning, pantomime is "more" symbolic than grooming, because pantomime involves acting on a non-present object, while for grooming actions, the body is present. Take "turning key" or "moving computer mouse" mimic actions; it is unlikely that infants have experience with these. Nonetheless, both require understanding the actor's intent.

deaf and hearing signers compared to non-signers (Bettger et al., 1997; McCullough and Emmorey, 1997; Bosworth and Dobkins, 2002; Stoll et al., 2018, 2019; Stoll and Dye, 2019).

Finally, we also found that sign-naïve 6-month-olds were drawn to look at the articulatory space while 11-month-olds were drawn to the face. In the present study, the body actions were produced in the absence of facial expressions and mouth movements, leaving only phonological information transmitted through hand configurations that change and move in relation to specific locations on the body. We also reported this early attention to manual articulators in sign-naïve infants using signed narratives (Stone and Bosworth, 2019) and ASL fingerspelling (Stone et al., 2018). The present findings of 11-month-olds looking heavily at the face, specifically the mouth, may be related to recent evidence of a developmental shift in infants' abilities to perceive audiovisual speech and their looking patterns while watching dynamic talker's faces (Lewkowicz and Ghazanfar, 2006; Pons et al., 2009; Lewkowicz et al., 2010; Grossmann et al., 2012; Lewkowicz, 2014). These studies show that when infants between 10 and 12 months perceive *unfamiliar* non-native speech, they look at the talker's mouth, but when they look at *familiar* talkers, they focus on the eyes. The explanation is put forth in those studies for this result is that those infants are exploring the mouth to help resolve uncertainty or confusion about the unfamiliar language input (Lewkowicz and Hansen-Tift, 2012). How could this explanation apply to the present findings in the case of sign language? Perhaps the 11-month-old infants tested here were also being presented with an *unfamiliar* visual language; hence, they look to the *mouth*. Importantly, 6-month-olds, however, look for *articulators*, and in the absence of movement on the mouth, they find it in the signing space that contains hands, while 11-month-olds look to the mouth because, for them, the mouth is their primary mode of articulation. This suggests an initial openness to explore possible articulators in multiple language modalities that attunes with age.

Several limitations need to be overcome in future work. First, it is worth mentioning the caveat common to infant perceptual studies. As with any study measuring looking behavior in infants, that an absence of differences in overt gaze across stimulus types reflects the absence of underlying sensitivity needs to be taken with a grain of salt. Of course, equal looking preferences or attention patterns may still result even if they can tell the difference between any two stimuli.

A second limitation is that we did not obtain concurrent measures of language development. We also did not obtain measures of stimulus comprehension in the native signing children. An important need to be addressed in future studies is the addition of visual attention measures, as in the present study, with concurrent and prospective measures of sign language outcomes (for discussion, see Henner et al., 2018). Measures of visual attention with overt gaze and eye movements do reflect underlying sign language proficiency in children (Lieberman et al., 2015, 2018; MacDonald et al., 2018, 2020). Gaze metrics have important utility because there is now substantial evidence that selective attention to language cues in the environment is tightly correlated with later social and language developmental outcomes (Tenenbaum et al., 2015; Tsang et al., 2018; Morin-Lessard et al., 2019). Moreover, the development of perception of body actions is important to study because this skill is one of the first prerequisite steps that support growing complexity in later expressive language skills and social development (Paulus et al., 2013). Another important consideration for future work is that children's experience of gesture varies across cultures, families, and individuals (Kendon, 2004) in a way that can impact young learners' perception of body actions.

## Conclusion

In the first year of life, infants actively attend to language cues, both visual and acoustic, in their environment and improve their perceptual abilities to recognize, discriminate, and categorize relevant language signals. Over time, the home language input changes their attention to these signals. Our study complements past findings, including those of infants' attention to the speaker's face, but also challenges interpretations to be broadened, as this body of research is typically framed in the context of speech processing. We found evidence that infants search for relevant linguistic information in either visual or auditory modalities. These results extend our understanding of infants' set of tools use for learning language; infants are guided to look for language signals in both the sign and speech.

Finally, it is worth noting that the non-signing and signing infants and children tested in the present study are similar in that all have full language access since birth. The CODA children tested in the present study showed typical development that is appropriate for their visual language modality, reflected in a refinement in the visual attention for visual body actions, suggesting an acquisition of amodal pragmatic skills for communication. That is not the case for most deaf children who are raised by non-signing hearing parents. The majority of children born deaf have parents who hear normally and do not sign (Humphries et al., 2012; Hall, 2017). These infants may be missing critical learning strategies that native signers quickly acquire shortly after birth (Mayberry, 2010). Deaf children who are not exposed to ASL may not learn to use their "perceptual span" to gather linguistic information effectively. That hearing infants were attentive to sign language cues, even if sign language is not their home language, suggests that all infants are receptive to language as visual or manual.

## Author's note

A video abstract of this article is available here: https://youtu.be/vQ8z5VDtxZs.

## Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## Ethics statement

The studies involving human participants were reviewed and approved by University of California, San Diego. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin. Written informed consent was obtained from the participants or minor(s)' legal guardian/next of kin for the publication of any potentially identifiable images or data included in this article.

## Author contributions

RGB collected the data. RGB and DPC wrote the manuscript. All authors designed the experiments and contributed to data analysis and manuscript and approved the submitted version.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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## Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2022.951057/full#supplementary-material

## References

Armstrong, D. F., and Wilcox, S. (2003). "Origins of sign languages," in *The Oxford Handbook of Deaf Studies, Language and Education*, 2 Edn, Vol. 1, eds M. Marschark and P. E. Spencer (New York, NY: Oxford University Press), 305–318.

Arterberry, M. E., and Bornstein, M. H. (2002). Infant perceptual and conceptual categorization: the roles of static and dynamic stimulus attributes. *Cognition* 86, 1–24. doi: 10.1016/s0010-0277(02)00108-7

Aslin, R. N. (2009). How infants view natural scenes gathered from a head-mounted camera. *Optom. Vis. Sci.* 86, 561–565.

Baker, S. A., Golinkoff, R. M., and Petitto, L. A. (2006). New insights into old puzzles from infants' categorical discrimination of soundless phonetic units. *Lang. Learn. Dev.* 2, 147–162. doi: 10.1207/s15473341lld0203_1

Baldwin, D. A. (2016). Interpersonal understanding fuels knowledge acquisition. *Curr. Direct. Psychol. Sci.* 9, 40–45. doi: 10.1111/1467-8721.00057

Behne, T., Carpenter, M., Call, J., and Tomasello, M. (2005). Unwilling versus unable: infants' understanding of intentional action. *Dev. Psychol.* 41, 328–337. doi: 10.1037/0012-1649.41.2.328

Bellugi, U., and Klima, E. S. (1982). *The Acquisition of Three Morphological Systems in American Sign Language Paper and Reports on Child Language Development*. Stanford, CA: Stanford University.

Berent, I., de la Cruz-Pavía, I., Brentari, D., and Gervain, J. (2021). Infants differentially extract rules from language. *Sci. Rep.* 11:20001. doi: 10.1038/s41598-021-99539-8

Bettger, J., Emmorey, K., McCullough, S., and Bellugi, U. (1997). Enhanced facial discrimination: effects of experience with American sign language. *J. Deaf. Stud. Deaf. Educ.* 2, 223–233. doi: 10.1093/oxfordjournals.deafed.a014328

Birules, J., Bosch, L., Brieke, R., Pons, F., and Lewkowicz, D. J. (2019). Inside bilingualism: language background modulates selective attention to a talker's mouth. *Dev. Sci.* 22:e12755. doi: 10.1111/desc.12755

Bosworth, R., Stone, A., and Hwang, S. O. (2020). Effects of video reversal on gaze patterns during signed narrative comprehension. *J. Deaf. Stud. Deaf. Educ.* 25, 283–297. doi: 10.1093/deafed/enaa007

Bosworth, R. G., and Dobkins, K. R. (2002). Visual field asymmetries for motion processing in deaf and hearing signers. *Brain Cogn.* 49, 170–181. doi: 10.1006/brcg.2001.1498

Bosworth, R. G., and Stone, A. (2021). Rapid development of perceptual gaze control in hearing native signing infants and children. *Dev. Sci.* 24:e13086. doi: 10.1111/desc.13086

Bosworth, R. G., Wright, C. E., and Dobkins, K. R. (2019). Analysis of the visual spatiotemporal properties of American sign language. *Vis. Res.* 164, 34–43. doi: 10.1016/j.visres.2019.08.008

Brentari, D. (2010). "Sign language prosodic cues in first and second language acquisition," in *Paper Presented at the Speech Prosody 2010-Fifth International Conference*, (Chicago, IL).

Brentari, D., Fenlon, J., and Cormier, K. (2018). "Sign language phonology," in *Oxford Research Encyclopedia of Linguistics*, ed. M. Aronoff (Berlin: De Gruyter Mouton), 21–54.

Brentari, D., Gonzalez, C., Seidl, A., and Wilbur, R. (2011). Sensitivity to visual prosodic cues in signers and nonsigners. *Lang. Speech* 54(Pt 1), 49–72. doi: 10.1177/0023830910388011

Brooks, R., and Meltzoff, A. N. (2008). Infant gaze following and pointing predict accelerated vocabulary growth through two years of age: a longitudinal, growth curve modeling study. *J. Child Lang.* 35, 207–220.

Brooks, R., Singleton, J. L., and Meltzoff, A. N. (2020). Enhanced gaze-following behavior in deaf infants of deaf parents. *Dev. Sci.* 23:e12900. doi: 10.1111/desc.12900

Cannon, E. N., and Woodward, A. L. (2012). Infants generate goal-based action predictions. *Dev. Sci.* 15, 292–298. doi: 10.1111/j.1467-7687.2011.01127.x

Caselli, N., Occhino, C., Artacho, B., Savakis, A., and Dye, M. (2022). Perceptual optimization of language: evidence from American sign language. *Cognition* 224:105040. doi: 10.1016/j.cognition.2022.105040

Chawarska, K., Macari, S., and Shic, F. (2013). Decreased spontaneous attention to social scenes in 6-month-old infants later diagnosed with autism spectrum disorders. *Biol. Psychiatry* 74, 195–203. doi: 10.1016/j.biopsych.2012.11.022

Christie, T., and Slaughter, V. (2010). Movement contributes to infants' recognition of the human form. *Cognition* 114, 329–337. doi: 10.1016/j.cognition.2009.10.004

Colombo, J., and Bundy, R. S. (1981). A method for the measurement of infant auditory selectivity. *Infant Behav. Dev.* 4, 219–223.

Corina, D. P., and Blau, S. (2016). "Neurobiology of sign languages," in *Neurobiology of Language*, eds G. Hickok and S. Small (Amsterdam: Elsevier), 431–443.

Corina, D. P., and Knapp, H. P. (2006). "Psycholinguistic and neurolinguistic perspectives on sign languages," in *Handbook of Psycholinguistics*, eds M. J. Traxler and M. A. Gernsbacher (Amsterdam: Elsevier), 1001–1024.

Corina, D. P., and Lawyer, L. A. (2019). "The neural organization of signed language," in *The Oxford Handbook of Neurolinguistics*, eds G. I. de Zubicaray and N. O. Schiller (New York, NY: Oxford University Press), 402–424.

Csibra, G., Bíró, S., Koós, O., and Gergely, G. (2003). One-year-old infants use teleological representations of actions productively. *Cogn. Sci.* 27, 111–133.

Daum, M. M., Vuori, M. T., Prinz, W., and Aschersleben, G. (2009). Inferring the size of a goal object from an actor's grasping movement in 6- and 9-month-old infants. *Dev. Sci.* 12, 854–862. doi: 10.1111/j.1467-7687.2009.00831.x

Dimitrova, N., Ozcaliskan, S., and Adamson, L. B. (2017). Do verbal children with autism comprehend gesture as readily as typically developing children? *J. Autism. Dev. Disord.* 47, 3267–3280. doi: 10.1007/s10803-017-3243-9

Dudis, P. G. (2004). *Depiction of Events in Asl: Conceptual Integration of Temporal Components* Ph. D Thesis. Berkeley, CA: University of California, Berkeley.

Emmorey, K. (1999). "Do signers gesture," in *Gesture, Speech, and Sign*, ed. L. M. A. R. Campbell (Washington, D.C: Gallaudet University Press), 133–159. doi: 10.1093/acprof:oso/9780198524519.003.0008pp

Emmorey, K. (2001). *Language, Cognition, and the Brain: Insights from Sign Language Research*. London: Psychology Press.

Frank, M. C., Amso, D., and Johnson, S. P. (2014). Visual search and attention to faces during early infancy. *J. Exp. Child Psychol.* 118, 13–26. doi: 10.1016/j.jecp.2013.08.012

Frank, M. C., Vul, E., and Johnson, S. P. (2009). Development of infants' attention to faces during the first year. *Cognition* 110, 160–170. doi: 10.1016/j.cognition.2008.11.010

Frank, M. C., Vul, E., and Saxe, R. (2012). Measuring the development of social attention using free-viewing. *Infancy* 17, 355–375.

Frishberg, N. (1975). Arbitrariness and iconicity: historical change in American sign language. *Language* 51, 696–719. doi: 10.2307/412894

Goldin-Meadow, S. (2005). *The Resilience of Language*. London: Psychology Press. doi: 10.4324/9780203943267

Goldin-Meadow, S., and Brentari, D. (2017). Gesture, sign, and language: the coming of age of sign language and gesture studies. *Behav. Brain Sci.* 40:e46. doi: 10.1017/S0140525X15001247

Goodrich, W., and Hudson Kam, C. L. (2009). Co-speech gesture as input in verb learning. *Dev. Sci.* 12, 81–87. doi: 10.1111/j.1467-7687.2008.00735.x

Grossmann, T., Missana, M., Friederici, A. D., and Ghazanfar, A. A. (2012). Neural correlates of perceptual narrowing in cross-species face-voice matching. *Dev. Sci.* 15, 830–839. doi: 10.1111/j.1467-7687.2012.01179.x

Hall, W. C. (2017). What you don't know can hurt you: the risk of language deprivation by impairing sign language development in deaf children. *Matern. Child Health J.* 21, 961–965. doi: 10.1007/s10995-017-2287-y

Hamlin, J. K., Hallinan, E. V., and Woodward, A. L. (2008). Do as i do: 7-month-old infants selectively reproduce others'. *Goals. Dev. Sci.* 11, 487–494. doi: 10.1111/j.1467-7687.2008.00694.x

Hannon, E. E., Schachner, A., and Nave-Blodgett, J. E. (2017). Babies know bad dancing when they see it: older but not younger infants discriminate between synchronous and asynchronous audiovisual musical displays. *J. Exp. Child Psychol.* 159, 159–174. doi: 10.1016/j.jecp.2017.01.006

Henderson, J. M. (2003). Human gaze control during real-world scene perception. *Trends Cogn. Sci.* 7, 498–504. doi: 10.1016/j.tics.2003.09.006

Henner, J., Novogrodsky, R., Reis, J., and Hoffmeister, R. (2018). Recent issues in the use of signed language assessments for diagnosis of language disorders in signing deaf and hard of hearing children. *J. Deaf Stud. Deaf Educ.* 23, 307–316. doi: 10.1093/deafed/eny014

Humphries, T., Kushalnagar, P., Mathur, G., Napoli, D. J., Padden, C., Rathmann, C., et al. (2012). Language acquisition for deaf children: reducing the harms of zero tolerance to the use of alternative approaches. *Harm Reduct. J.* 9:16.

Jusczyk, P. W. (1997). *The Discovery of Spoken Language Bradford Books*. Cambridge MA: MIT Press.

Jusczyk, P. W. (2016). How infants adapt speech-processing capacities to native-language structure. *Curr. Direct. Psychol. Sci.* 11, 15–18. doi: 10.1111/1467-8721.00159

Kaufman, A. S., and Kaufman, N. L. (2004). *Kaufman Brief Intelligence Test*, 2nd Edn. Bloomington, MN: Pearson, Inc.

Kegl, J., Senghas, A., and Coppola, M. (1999). "Creation through contact: sign language emergence and sign language change in nicaragua," in *Language Creation and Language Change: Creolization, Diachrony, and Development*, ed. M. de Graff (Cambridge, MA: MIT Press), 179–237.

Kendon, A. (2004). *Gesture: Visible Action as Utterance*. Cambridge: Cambridge University Press, doi: 10.1017/cbo9780511807572

Klima, E. S., and Bellugi, U. (1979). *The Signs of Language*. Cambridge. MA: Harvard University Press.

Komori, N. (2006). "Do infants prefer possible human movements?," in *Paper presented at the Proceedings of the 5th International Conference on Cognitive Science*, (Vancouver, BC).

Krentz, U. C., and Corina, D. P. (2008). Preference for language in early infancy: the human language bias is not speech specific. *Dev. Sci.* 11, 1–9. doi: 10.1111/j.1467-7687.2007.00652.x

Kuhl, P., and Rivera-Gaxiola, M. (2008). Neural substrates of language acquisition. *Annu. Rev. Neurosci.* 31, 511–534. doi: 10.1146/annurev.neuro.30.051606.094321

Kuhl, P. K. (2004). Early language acquisition: cracking the speech code. *Nat. Rev. Neurosci.* 5, 831–843. doi: 10.1038/nrn1533

Kuhl, P. K., Williams, K. A., Lacerda, F., Stevens, K. N., and Lindblom, B. (1992). Linguistic experience alters phonetic perception in infants by 6 months of age. *Science* 255, 606–608. doi: 10.1126/science.1736364

Lepic, R., and Occhino, C. (2018). "A construction morphology approach to sign language analysis," in *The Construction of Words*, ed. G. Booij (Berlin: Springer), 141–172.

Lewkowicz, D. J. (2014). Early experience and multisensory perceptual narrowing. *Dev. Psychobiol.* 56, 292–315. doi: 10.1002/dev.21197

Lewkowicz, D. J., and Ghazanfar, A. A. (2006). The decline of cross-species intersensory perception in human infants. *Proc. Natl. Acad. Sci. U.S.A.* 103, 6771–6774. doi: 10.1073/pnas.0602027103

Lewkowicz, D. J., and Hansen-Tift, A. M. (2012). Infants deploy selective attention to the mouth of a talking face when learning speech. *Proc. Natl. Acad. Sci. U.S.A.* 109, 1431–1436. doi: 10.1073/pnas.1114783109

Lewkowicz, D. J., Leo, I., and Simion, F. (2010). Intersensory perception at birth: newborns match nonhuman primate faces and voices. *Infancy* 15, 46–60. doi: 10.1111/j.1532-7078.2009.00005.x

Lieberman, A. M., Borovsky, A., Hatrak, M., and Mayberry, R. I. (2015). Real-time processing of asl signs: delayed first language acquisition affects organization of the mental lexicon. *J. Exp. Psychol. Learn. Mem. Cogn.* 41, 1130–1139. doi: 10.1037/xlm0000088

Lieberman, A. M., Borovsky, A., and Mayberry, R. I. (2018). Prediction in a visual language: real-time sentence processing in American sign language across development. *Lang. Cogn. Neurosci.* 33, 387–401. doi: 10.1080/23273798.2017.1411961

Lillo-Martin, D. (1999). Modality effects and modularity in language acquisition: the acquisition of American sign language. *Hand. Child Lang. Acquisit.* 531:567.

MacDonald, K., LaMarr, T., Corina, D., Marchman, V. A., and Fernald, A. (2018). Real-time lexical comprehension in young children learning american sign language. *Dev. Sci.* 21:e12672. doi: 10.1111/desc.12672

MacDonald, K., Marchman, V. A., Fernald, A., and Frank, M. C. (2020). Children flexibly seek visual information to support signed and spoken language comprehension. *J. Exp. Psychol. Gen.* 149, 1078–1096. doi: 10.1037/xge0000702

MacSweeney, M., Campbell, R., Woll, B., Giampietro, V., David, A. S., McGuire, P. K., et al. (2004). Dissociating linguistic and nonlinguistic gestural communication in the brain. *Neuroimage* 22, 1605–1618. doi: 10.1016/j.neuroimage.2004.03.015

Mayberry, R. I. (2010). "Early language acquisition and adult language ability: what sign language reveals about the critical period about the critical," in *The Oxford Handbook of Deaf Studies, Language, and Education*, Vol. 2, eds M. Marschark and P. Spencer (New York, NY: Oxford University Press), 281–291. doi: 10.1093/oxfordhb/9780195390032.013.0019

Mayberry, R. I., and Squires, B. (2006). Sign language acquisition. *Encyclop. Lang. Linguist.* 11, 739–743.

McCullough, S., and Emmorey, K. (1997). Face processing by deaf asl signers: evidence for expertise in distinguished local features. *J. Deaf Stud. Deaf Educ.* 2, 212–222. doi: 10.1093/oxfordjournals.deafed.a014327

McNeill, D. (1992). *Hand and Mind: What Gestures Reveal About Thought*. Chicago, IL: University of Chicago Press.

Mehler, J., Jusczyk, P., Lambertz, G., Halsted, N., Bertoncini, J., and Amiel-Tison, C. (1988). A precursor of language acquisition in young infants. *Cognition* 29, 143–178. doi: 10.1016/0010-0277(88)90035-2

Meier, R. (2002). The acquisition of verb agreement: pointing out arguments for the linguistic status. *Direct. Sign Lang. Acquisit.* 2:115.

Meltzoff, A. N. (1995). Understanding the intentions of others: re-enactment of intended acts by 18-month-old children. *Dev. Psychol.* 31, 838–850. doi: 10.1037/0012-1649.31.5.838

Meltzoff, A. N. (1999). Origins of theory of mind, cognition and communication. *J. Commun. Disord.* 32, 251–269. doi: 10.1016/s0021-9924(99)00009-x

Mercure, E., Kushnerenko, E., Goldberg, L., Bowden-Howl, H., Coulson, K., Johnson, M. H., et al. (2019). Language experience influences audiovisual speech integration in unimodal and bimodal bilingual infants. *Dev. Sci.* 22:e12701. doi: 10.1111/desc.12701

Mercure, E., Quiroz, I., Goldberg, L., Bowden-Howl, H., Coulson, K., Gliga, T., et al. (2018). Impact of language experience on attention to faces in infancy: evidence from unimodal and bimodal bilingual infants. *Front. Psychol.* 9:1943. doi: 10.3389/fpsyg.2018.01943

Morales, M., Mundy, P., and Rojas, J. (1998). Following the direction of gaze and language development in 6-month-olds. *Infant Behav. Dev.* 21, 373–377.

Morford, J. P., and Kegl, J. A. (2000). Gestural precursors to linguistic constructs: how input shapes the form of language. *Lang. Gest.* 2:358.

Morin-Lessard, E., Poulin-Dubois, D., Segalowitz, N., and Byers-Heinlein, K. (2019). Selective Attention to the Mouth of Talking Faces in Monolinguals and Bilinguals Aged 5 Months to 5 Years. *Dev Psychol* 55, 1640–1655. doi: 10.1037/dev0000750

Morita, T., Slaughter, V., Katayama, N., Kitazaki, M., Kakigi, R., and Itakura, S. (2012). Infant and adult perceptions of possible and impossible body movements: an eye-tracking study. *J. Exp. Child Psychol.* 113, 401–414. doi: 10.1016/j.jecp.2012.07.003

Namy, L. L. (2008). Recognition of iconicity doesn't come for free. *Dev. Sci.* 11, 841–846. doi: 10.1111/j.1467-7687.2008.00732.x

Nazzi, T., Bertoncini, J., and Mehler, J. (1998). Language discrimination by newborns: toward an understanding of the role of rhythm. *J. Exp. Psychol. Hum. Percept. Perform.* 24, 756–766. doi: 10.1037//0096-1523.24.3.756

Nazzi, T., Nelson, D. G. K., Jusczyk, P. W., and Jusczyk, A. M. (2000). Six-month-olds' detection of clauses embedded in continuous speech: effects of prosodic well-formedness. *Infancy* 1, 123–147.

Nespor, M., and Sandler, W. (1999). Prosody in Israeli sign language. *Lang. Speech* 42, 143–176.

Newport, E. L., and Meier, R. P. (1985). "The acquisition of american sign language," in *The Cross-Linguistic Study of Language Acquisition*, Vol. 1, ed. D. I. Slobin (Hillsdale, NJ: Lawrence Erlbaum Associates, Inc), 881–938.

Newport, E. L., and Meier, R. P. (2017). "The acquisition of american sign language," in *The Cross-linguistic Study of Language Acquisition*, ed. D. I. Slobin (London: Psychology Press), 881–938.

Novack, M. A., Filippi, C. A., Goldin-Meadow, S., and Woodward, A. L. (2018). Actions speak louder than gestures when you are 2 years old. *Dev. Psychol.* 54:1809.

Novack, M. A., and Goldin-Meadow, S. (2017). Gesture as representational action: a paper about function. *Psychon. Bull. Rev.* 24, 652–665. doi: 10.3758/s13423-016-1145-z

Ortega, G. (2017). Iconicity and sign lexical acquisition: a review. *Front. Psychol.* 8:1280. doi: 10.3389/fpsyg.2017.0128

Palmer, S. B., Fais, L., Golinkoff, R. M., and Werker, J. F. (2012). Perceptual narrowing of linguistic sign occurs in the 1st year of life. *Child Dev.* 83, 543–553. doi: 10.1111/j.1467-8624.2011.01715.x

Palmer, S. D., van Hooff, J. C., and Havelka, J. (2010). Language representation and processing in fluent bilinguals: electrophysiological evidence for asymmetric mapping in bilingual memory. *Neuropsychologia* 48, 1426–1437. doi: 10.1016/j.neuropsychologia.2010.01.010

Paulus, M., Hunnius, S., and Bekkering, H. (2013). Neurocognitive mechanisms underlying social learning in infancy: infants' neural processing of the effects of others' actions. *Soc. Cogn. Affect. Neurosci.* 8, 774–779. doi: 10.1093/scan/nss065

Peltola, M. J., Yrttiaho, S., and Leppanen, J. M. (2018). Infants' attention bias to faces as an early marker of social development. *Dev. Sci.* 21:e12687. doi: 10.1111/desc.12687

Perszyk, D. R., and Waxman, S. R. (2018). Linking language and cognition in infancy. *Annu. Rev. Psychol.* 69, 231–250.

Petitto, L. A., and Marentette, P. F. (1991). Babbling in the manual mode: evidence for the ontogeny of language. *Science* 251, 1493–1496. doi: 10.1126/science.2006424

Pfau, R., Steinbach, M., and Woll, B. (2012). *Sign Language: An International Handbook*. Berlin: De Gruyter Mouton, doi: 10.1515/9783110261325

Phillips, A. T., and Wellman, H. M. (2005). Infants' understanding of object-directed action. *Cognition* 98, 137–155. doi: 10.1016/j.cognition.2004.11.005

Pichler, D. C., Lillo-Martin, D., de Quadros, R. M., and Stumpf, M. R. (2018). *Sign Language Acquisition by Deaf and Hearing Children*. Washington, DC: Gallaudet University Press.

Pons, F., Bosch, L., and Lewkowicz, D. J. (2015). Bilingualism modulates infants' selective attention to the mouth of a talking face. *Psychol. Sci.* 26, 490–498. doi: 10.1177/0956797614568320

Pons, F., Lewkowicz, D. J., Soto-Faraco, S., and Sebastian-Galles, N. (2009). Narrowing of intersensory speech perception in infancy. *Proc. Natl. Acad. Sci. U.S.A.* 106, 10598–10602. doi: 10.1073/pnas.0904134106

Reddy, V., Markova, G., and Wallot, S. (2013). Anticipatory adjustments to being picked up in infancy. *PLoS One* 8:e65289. doi: 10.1371/journal.pone.0065289

Reid, V. M., Csibra, G., Belsky, J., and Johnson, M. H. (2007). Neural correlates of the perception of goal-directed action in infants. *Acta Psychol. (Amst)* 124, 129–138. doi: 10.1016/j.actpsy.2006.09.010

Reynolds, G. D., and Roth, K. C. (2018). The development of attentional biases for faces in infancy: a developmental systems perspective. *Front. Psychol.* 9:222. doi: 10.3389/fpsyg.2018.00222

Rinaldi, P., Caselli, M. C., Di Renzo, A., Gulli, T., and Volterra, V. (2014). Sign vocabulary in deaf toddlers exposed to sign language since birth. *J. Deaf Stud. Deaf Educ.* 19, 303–318. doi: 10.1093/deafed/enu007

Rutherford, M. D., Walsh, J. A., and Lee, V. (2015). Brief report: infants developing with asd show a unique developmental pattern of facial feature scanning. *J. Autism. Dev. Disord.* 45, 2618–2623. doi: 10.1007/s10803-015-2396-7

Saffran, J. R., Aslin, R. N., and Newport, E. L. (1996). Statistical learning by 8-month-old infants. *Science* 274, 1926–1928.

Sandler, W., and Lillo-Martin, D. (2006). *Sign Language and Linguistic Universals*. Cambridge: Cambridge University Press.

Sandler, W., Meir, I., Padden, C., and Aronoff, M. (2005). The emergence of grammar: systematic structure in a new language. *Proc. Natl. Acad. Sci. U.S.A.* 102, 2661–2665. doi: 10.1073/pnas.0405448102

Sehyr, Z. S., Caselli, N., Cohen-Goldberg, A. M., and Emmorey, K. (2021). The Asl-Lex 2.0 project: a database of lexical and phonological properties for 2,723 signs in american sign language. *J. Deaf Stud. Deaf Educ.* 26, 263–277.

Senghas, A. (2005). Language emergence: clues from a new bedouin sign. *Curr. Biol.* 15, R463–R465. doi: 10.1016/j.cub.2005.06.018

Slater, A., Morison, V., Somers, M., Mattock, A., Brown, E., and Taylor, D. (1990). Newborn and older infants' perception of partly occluded objects. *Infant Behav. Dev.* 13, 33–49. doi: 10.1016/0163-6383(90)90004-r

Slaughter, V., and Heron-Delaney, M. (2011). When do infants expect hands to be connected to a person? *J. Exp. Child Psychol.* 108, 220–227.

Stokoe, W. (1960). *Sign Language Structure, an Outline of the Visual Communications Systems of American Deaf. Studies in Linguistics Occasional Paper*, Vol. 8. Buffalo, NY: University of Buffalo.

Stokoe, W. C., Casterline, D. C., and Croneberg, C. G. (1976). *A Dictionary of American Sign Language on Linguistic Principles*. Silver Spring, MD: Linstok Press.

Stoll, C., and Dye, M. W. G. (2019). Sign language experience redistributes attentional resources to the inferior visual field. *Cognition* 191:103957. doi: 10.1016/j.cognition.2019.04.026

Stoll, C., Palluel-Germain, R., Caldara, R., Lao, J., Dye, M. W. G., Aptel, F., et al. (2018). Face recognition is shaped by the use of sign language. *J. Deaf Stud. Deaf Educ.* 23, 62–70. doi: 10.1093/deafed/enx034

Stoll, C., Rodger, H., Lao, J., Richoz, A. R., Pascalis, O., Dye, M., et al. (2019). Quantifying facial expression intensity and signal use in deaf signers. *J. Deaf Stud. Deaf Educ.* 24, 346–355. doi: 10.1093/deafed/enz023

Stone, A., and Bosworth, R. G. (2019). Exploring infant sensitivity to visual language using eye tracking and the preferential looking paradigm. *J. Vis. Exp.* 147:e59581. doi: 10.3791/59581

Stone, A., Petitto, L. A., and Bosworth, R. (2018). Visual sonority modulates infants' attraction to sign language. *Lang. Learn. Dev.* 14, 130–148. doi: 10.1080/15475441.2017.1404468

Tees, R. C., and Werker, J. F. (1984). Perceptual flexibility: maintenance or recovery of the ability to discriminate non-native speech sounds. *Can. J. Psychol.* 38, 579–590. doi: 10.1037/h0080868

Tenenbaum, E. J., Amso, D., Abar, B., and Sheinkopf, S. J. (2014). Attention and word learning in autistic, language delayed and typically developing children. *Front. Psychol.* 5:490. doi: 10.3389/fpsyg.2014.00490

Tenenbaum, E. J., Shah, R. J., Sobel, D. M., Malle, B. F., and Morgan, J. L. (2013). Increased focus on the mouth among infants in the first year of life: a longitudinal eye-tracking study. *Infancy* 18, 534–553. doi: 10.1111/j.1532-7078.2012.00135.x

Tenenbaum, E. J., Sobel, D. M., Sheinkopf, S. J., Shah, R. J., Malle, B. F., and Morgan, J. L. (2015). Attention to the mouth and gaze following in infancy predict language development. *J. Child Lang.* 42, 1173–1190. doi: 10.1017/S0305000914000725

Tomasello, M. (1999). "Having intentions, understanding intentions, and understanding communicative intentions," in *Developing Theories of Intention: Social Understanding and Self-Control*, eds P. D. Zelazo, J. W. Astington, and D. R. Olson (Hillsdale, NJ: Lawrence Erlbaum Associates Publishers), 63–75.

Tsang, T., Atagi, N., and Johnson, S. P. (2018). Selective attention to the mouth is associated with expressive language skills in monolingual and bilingual infants. *J. Exp. Child Psychol.* 169, 93–109.

Vouloumanos, A., and Werker, J. F. (2004). Tuned to the signal: the privileged status of speech for young infants. *Dev. Sci.* 7, 270–276. doi: 10.1111/j.1467-7687.2004.00345.x

Weikum, W. M., Vouloumanos, A., Navarra, J., Soto-Faraco, S., Sebastian-Galles, N., and Werker, J. F. (2007). Visual language discrimination in infancy. *Science* 316:1159. doi: 10.1126/science.1137686

Wellman, H. M., and Phillips, A. T. (2001). "Developing intentional understandings," in *Intentions and Intentionality: Foundations of Social Cognition*, Vol. 1, eds B. Malle, L. Moses, and D. Baldwin (Cambridge, MA: The MIT Press), 125–148.

Werker, J. F., and Curtin, S. (2005). Primir: a developmental framework of infant speech processing. *Lang. Learn. Dev.* 1, 197–234.

Werker, J. F., and Tees, R. C. (1984). Phonemic and phonetic factors in adult cross-language speech perception. *J. Acoust. Soc. Am.* 75, 1866–1878. doi: 10.1121/1.390988

Wilbur, R. B. (1979). *American Sign Language and Sign Systems*. University Park, PA: University Park Press.

Wilcox, S., and Occhino, C. (2016). Constructing signs: place as a symbolic structure in signed languages. *Cogn. Linguist.* 27, 371–404. doi: 10.1515/cog-2016-0003

Woodward, A., Sommerville, J., and Guajardo, J. (2001). "How infants make sense of intentional action," in *Intentions and Intentionality Foundations of Social Cognition*, eds B. F. Malle, L. J. Moses, and D. A. Baldwin (Berlin: The MIT Press).

Woodward, A. L. (1998). Infants selectively encode the goal object of an actor's reach. *Cognition* 69, 1–34. doi: 10.1016/s0010-0277(98)00058-4

Yeung, H. H., and Werker, J. F. (2009). Learning words' sounds before learning how words sound: 9-month-olds use distinct objects as cues to categorize speech information. *Cognition* 113, 234–243.

Young, G. S., Merin, N., Rogers, S. J., and Ozonoff, S. (2009). Gaze behavior and affect at 6 months: predicting clinical outcomes and language development in typically developing infants and infants at risk for autism. *Dev. Sci.* 12, 798–814. doi: 10.1111/j.1467-7687.2009.00833.x

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# Language aptitude in the visuospatial modality: L2 British Sign Language acquisition and cognitive skills in British Sign Language-English interpreting students

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Sign language interpreting (SLI) is a cognitively challenging task performed mostly by second language learners (i.e., not raised using a sign language as a home language). SLI students must first gain language fluency in a new visuospatial modality and then move between spoken and signed modalities as they interpret. As a result, many students plateau before reaching working fluency, and SLI training program drop-out rates are high. However, we know little about the requisite skills to become a successful interpreter: the few existing studies investigating SLI aptitude in terms of linguistic and cognitive skills lack baseline measures. Here we report a 3-year exploratory longitudinal skills assessments study with British Sign Language (BSL)-English SLI students at two universities ($n$ = 33). Our aims were two-fold: first, to better understand the prerequisite skills that lead to successful SLI outcomes; second, to better understand how signing and interpreting skills impact other aspects of cognition. A battery of tasks was completed at four time points to assess skills, including but not limited to: multimodal and unimodal working memory, 2-dimensional and 3-dimensional mental rotation (MR), and English comprehension. Dependent measures were BSL and SLI course grades, BSL reproduction tests, and consecutive SLI tasks. Results reveal that initial BSL proficiency and 2D-MR were associated with selection for the degree program, while visuospatial working memory was linked to continuing with the program. 3D-MR improved throughout the degree, alongside some limited gains in auditory, visuospatial, and multimodal working memory tasks. Visuospatial working memory and MR were the skills closest associated with BSL and SLI outcomes, particularly those tasks involving sign language production, thus, highlighting the importance of cognition related to the visuospatial modality. These preliminary data will inform SLI training programs, from applicant selection to curriculum design.

KEYWORDS

**sign language, interpreting, cognition, language aptitude, L2 acquisition**

# Introduction

## Background and situation of sign language interpreting training in universities

Sign language interpreting (SLI) is known to be a uniquely challenging task, but few studies have investigated the linguistic and cognitive skills that make a prospective student interpreter more likely to succeed. In Great Britain, one of the main routes to becoming a sign language interpreter is completing a 3- to 4-year SLI undergraduate degree, where students acquire the target sign language (British Sign Language; BSL) alongside developing their interpreting skills. Both sign language learning and learning to interpret are challenging and distinct endeavors and likely due to these challenges, SLI degree programs suffer from high drop-out rates (see e.g., Grbić, 2009; Leitner, 2012; Huhtinen, 2014). First, unlike spoken language interpretation, where many interpreters are bilingual in both their working languages from an early age, the majority of SLI students do not enter programs with pre-existing sign language fluency and, thus, their initial second language (L2) acquisition occurs within a university, and not community, context (Cokely, 1986; Peterson, 1999; Monikowski and Peterson, 2005). Furthermore, there may be special challenges involved in learning an L2 in a different modality. Concerningly, there is evidence that the academic demands of SLI degrees mean that students have fewer opportunities to engage with the deaf community (Pivac, 2014); that SLI students overestimate their sign language fluency and interpreting skills (Beal et al., 2018; Robinson and Henner, 2018); and that many do not attain working sign language fluency even by the end of their degree programs (see e.g., Volk, 2014). Together, these contribute to a gap between SLI training completion and competent practice (Witter-Merithew and Johnson, 2005).

As well as learning an L2 in a new modality during their degree program, SLI students also must learn how to interpret. SLI is both cognitively and linguistically demanding, involving the simultaneous use of two languages in two different modalities (Padden, 2000). However, there is minimal research into whether a cognitive aptitude profile exists for L2 SLI students embarking on the study to reach professional fluency. Here, we follow López Gómez et al. (2007), who found that perceptual-motor skills and cognitive verbal abilities played a greater role than personality in predicting SLI students' sign language proficiency, suggesting that greater focus should be placed on cognitive predictors of signing and interpreting outcomes, as does Stone (2017). While a lot of research on cognitive aptitude for spoken interpreters exists, some of this is modality-specific and only applicable to the spoken-language aspects of SLI. It is also less informative regarding the cognitive and linguistic skills required to interpret sign language in the visuospatial modality. Another important difference is that spoken language interpreters work primarily from their L2 into their L1, whereas most signed language interpreters work primarily from spoken L1 into signed L2 (Nicodemus and Emmorey, 2013). Assessing linguistic and cognitive aptitude for SLI prior to entry into interpreter training programs could help reduce drop-out rates, minimize the rehousing of struggling SLI degree students into Deaf Studies programs (Stone, 2017), and would ultimately save a lot of time, both for instructors and students. According to Grbić (2009), beginner SLI students are often motivated by "social goodwill" but are less aware of the cognitive, social, and emotional demands of SLI, which initial pre-screening may help to highlight. Assessment at intake is, thus, not aimed at discouraging L2 sign language learning or potential SLI students, but, instead, encourages them to recognize as early as possible that SLI is challenging for various reasons.

Importantly, incomplete L2 sign language acquisition or insufficient skill in interpreting results in a lack of language access for deaf people who may use SLI services and when interacting with hearing people who do not sign. In the United Kingdom (UK), demand for SLI services frequently exceeds supply (Department for Work and Pensions [DWP], 2017). This can, in turn, lead to the use of unqualified, non-professional language brokers who do not meet the national standards for interpreting (CFA, 2012). Understanding the linguistic and cognitive factors that are important for both successful L2 sign language acquisition and high-level interpreting, is, thus key to improving access for deaf people.

Furthermore, training SLI students involves a significant financial investment. Whether students self-funded their studies or are supported by government grants, it is vital to ensure that the limited resources in SLI training (Webb, 2017) are used sensibly, and those students with optimum potential are supported. As Hunt and Nicodemus (2014) point out: "[o]ne of the problems with gatekeeping is timing; by the time a student gives evidence that they are not suitable, they have already invested a great deal of time and money in their degree." While aptitude testing on admission is considered integral and is a standard practice in spoken language interpreting courses (see, e.g., Timarová and Ungoed-Thomas, 2008), SLI degree programs in the UK do not presently use any research-informed methods to test applicants in terms of their suitability (Stone, 2017). In the United States, the assessment of cognitive skills was found to be only a minor aspect of SLI programs' entrance requirements (Marks, 2014), with most institutions focusing only on American Sign Language (ASL) and English skills. In Australia, initial SLI degree screening has been found to be informal and is often not evidence-based (Bontempo and Napier, 2009). Initial data highlighting which cognitive and linguistic assessments are likely related to SLI aptitude would therefore also be a benefit to prospective students and SLI programs.

## Cognitive and linguistic skills in spoken language interpreting

In spoken language interpreting, it has long been known that cognitive skills like working memory and cognitive load are vital to the interpreting process (see, e.g., Gile, 1997) and thus an important consideration for interpreter educators. As a result, cognitive aptitude for spoken language interpreting has been investigated to a greater extent than for SLI, with research now spanning several decades (for review, see Russo, 2011). This means that some aptitude test batteries have been validated for their reliability and are now widely used to screen spoken language interpreting trainee candidates or for intensive language training programs. For example, many interpreter training programs use long-standing commercial aptitude batteries like the Modern Language Aptitude Test (MLAT, Carroll and Sapon, 1959; Carroll et al., 2010) or the Pimsleur Language Aptitude Battery (Pimsleur, 1966), which include tasks involving learning new vocabulary and phonetic discrimination, among others.

More recently, research has focused particularly on the importance of working memory (WM) in spoken language interpreting, however, the findings are mixed. Both improvements in WM after interpreting training (Christoffels et al., 2006; Babcock et al., 2017; Chmiel, 2018) and WM effects on simultaneous interpreting fluency (Lin et al., 2018) have been reported. Auditory WM has also been shown to be more important than social factors like personality in simultaneous spoken language interpreting (Anssari-Naim, 2021), and L2 auditory WM is correlated with consecutive interpreting performance (Dong et al., 2018). However, some studies found no effects of WM: for example, professional interpreters were no different in general WM capacity from beginner interpreter students (Liu et al., 2004); linguistic factors, such as word knowledge in L1 and L2, were more important for interpreting performance than increased WM capacity (e.g., Padilla et al., 2005), and interpreting training has been found to improve language processing skills, but not WM (Tzou et al., 2012). In terms of other cognitive skills, spoken language interpreters have been shown to have superior cognitive flexibility over bilinguals with no interpreting training (Yudes et al., 2011), as well as superior dual-task attention compared to non-interpreters (Morales et al., 2015; Strobach et al., 2015). Macnamara (2009) also provides a review of cognitive functions and capacities required for interpreting, including chunking, online decision-making, and processing speed.

In this preliminary study, we focus on sign language interpreters who, like spoken language interpreters, make use of auditory WM, but also need to rely on visuospatial WM. According to Baddeley's model of WM (Baddeley et al., 2009; Baddeley, 2012), auditory memory and visual memory are maintained through separate functional components: the phonological loop, and the visual sketchpad, respectively. This suggests that there may be different memory requirements or processes for SLI compared to spoken language interpreting, given the different modalities that must be attended to.

## Existing work on linguistic and cognitive aptitude for sign language interpreting

As with spoken language interpreting, there has been a long-standing interest in establishing which skills are required to be successful in SLI (for review, see Nakano, 2021). Some studies have taken the approach of surveying and studying the attributes of qualified sign language interpreters (e.g., Jones and Quigley, 1974; Seal, 2004; Shaw and Hughes, 2006), the latter finding that visual attention while inhibiting distractors was a particularly important skill. Other studies have compared skills in signed and spoken language interpretating students. For example, Shaw (2011) found better visual memory skills and concentration in SLI students than in spoken language interpreting students, both in terms of longer retention of visual information and better performance when visual distractors were present. Other linguistic and cognitive aptitudes that have been mentioned in the literature for both spoken language interpreting and SLI include a high command of both working languages, verbal fluency, processing speed, good WM, and concentration. For SLI alone, a further factor was the capacity to sign and talk simultaneously (Frishberg, 1986; Lara Burgos and de los Santos Rodríguez, 2000; cited in López Gómez et al., 2007).

Researchers have also explored the role of WM in SLI, again with mixed results. Wang (2016) found no evidence that auditory WM capacity in English or visual WM in Auslan was related to SLI task performance in either direction. However, van Dijk et al. (2012) found that auditory WM span in Dutch and visual WM in Sign Language of the Netherlands (NGT) were related to the quality of interpretations by NGT-Dutch interpreters. Looking at domain-general cognitive skills beyond WM, Macnamara et al. (2011) found that highly-skilled ASL-English interpreters had greater mental flexibility, faster cognitive processing, and psychomotor speed, and were better at task-switching when compared to less-skilled interpreters. Haug et al. (2019a,b) described initial data from working Swiss German Sign Language (DSGS)-German interpreters on a battery of cognitive tasks, developing their versions of WM tasks featuring DSGS stimuli. Their preliminary results suggest that the cognitive abilities of interpreters on all normed tests are above average, and that weaknesses or average performance in certain cognitive areas may be compensated by strengths in others. Studies on cognition in qualified working interpreters can inform us about the 'end results' of SLI training and professional experience, but are less informative regarding prospective SLI students: it is not clear which skills were improved through SLI training or professional experience, or if some skills are foundational and should ideally be at a threshold level at the outset of learning.

In terms of students, some SLI educators have administered broad pre-admission test batteries before SLI training, finding predictive relationships between performance in the screening battery and later SLI outcomes (e.g., Humphrey, 1994; Bontempo and Napier, 2009). However, only the cumulative effect of the test batteries is discussed and not the individual assessments, meaning it is hard to be certain what to attribute the predictive power to nor were the test batteries re-administered at later points to understand progression in different areas. To our knowledge, there have only been a few studies that have investigated the cognitive aptitude of SLI trainees throughout their studies (López Gómez et al., 2007; Macnamara and Conway, 2016; Stone, 2017). López Gómez et al. (2007) found that a nonsense-sign repetition test was a good predictor of successful Spanish Sign Language acquisition, whereas, for Stone's cohort, the MLAT number-learning test was predictive of students' BSL exam results. Both studies argued that these tasks directly or indirectly relate to how the phonological structure of signs is encoded. L2 sign language learners are known to struggle with phonological processing in the new visuospatial modality (e.g., Ortega and Morgan, 2015; Williams and Newman, 2016). This has also been shown in deaf signers who learn sign language as an L2 or late L1 and experience a 'processing bottleneck' at the phonological level (Mayberry and Fischer, 1989). Another study that has taken a re-test approach to cognition in SLI trainees is Macnamara and Conway (2016), who administered a battery of cognitive tests targeting WM capacity and SLI performance at four points throughout an ASL-English SLI training program. Their main findings were that WM capacity predicted initial SLI performance and that it was an even stronger predictor of final SLI performance. Additionally, students who performed well initially maintained a high level of performance, whereas those who performed poorly initially benefited more from the SLI training, but not enough to catch up to the higher level. Despite these initial longitudinal investigations into student SLI cognitive aptitude, none of these studies assessed students' baseline skills before the start of their program, meaning that performance could have been already changed by sign language teaching or other factors.

## Cognitive adaptations from L2 sign learning

Research has shown that fluent signers outperform non-signers on several measures of visuospatial ability like mental rotation (MR) and image generation (for review, see Emmorey, 1998, 2002), suggesting skills-based enhancements from exposure to language in the visuospatial modality. Particularly, MR has been shown numerous times to be improved because of sign language experience (e.g., McKee, 1987; Talbot and Haude, 1993; Emmorey et al., 1998), indicating it is an important skill required for sign language use. As well as the need to mentally rotate to understand, e.g., topographical uses of signing space, Watkins et al. (2018) also suggest that MR skills are crucial to BSL comprehension when perceiving signs from the side, as opposed to a face-to-face orientation. Side-on comprehension is needed in many real-life situations, e.g., group conversations, or SLI scenarios, such as conferences, yet is often neglected in teaching materials and methods, where incidental side-on comprehension in class is relied upon, rather than being specifically instructed.

Some skill-based enhancements in visuospatial WM and MR extend into late L2 signers (e.g., Keehner and Gathercole, 2007; Kubicek and Quandt, 2021). However, like many interpreting aptitude studies, they lack baseline measures before sign learning or critical SLI instruction began. For example, Keehner and Gathercole found improved visuospatial WM in fluent late L2 signers working as BSL interpreters, but the authors acknowledge that their participants may simply have been spatially adept before learning to sign, which, in turn, may have facilitated successful L2 sign language acquisition. Thus, it is unclear whether such effects derive directly from signing experience, or whether those reaching fluency are predisposed to better cognitive abilities, such as MR or visuospatial WM. If pre-existing threshold visuospatial skills are found to be predictive of successful L2 sign language learning, these could then be targeted for specific training, either within a signing context or as a general cognitive skill, within SLI training programs. It has already been shown that deaf and hard of hearing children can improve their MR skills through targeted practice (Passig and Eden, 2001), which then feeds back into sign language fluency. An advantage of a longitudinal approach with a baseline measure at the start of the SLI program means we can detect both how skills progress across time, and how individual differences in baseline skills relate to this development.

## Present study and domains of investigation

Longitudinal studies are a good approach for investigating aptitude and related questions, as they allow the identification of developmental milestones and any individual differences in performance, as well as the time points at which learners begin to perform at the level of working interpreters.

One open question is the link between WM and modality in SLI (for further discussion, see also Wilson and Emmorey, 2003; Hall and Bavelier, 2011; Wang and Napier, 2013; Williams et al., 2015). Existing studies have not always distinguished between multimodal dual-attention WM tasks requiring both auditory and visuospatial attention, and unimodal WM tasks where only one modality must be attended to. Furthermore, most of the aforementioned research on SLI and WM only includes a single WM task in just one modality, and overall, very few studies have employed multimodal WM tasks. One exception is Bontempo and Napier (2009), who included a dual-task memory exercise (divided attention) in their pre-SLI-degree test battery, but they did not describe the results at a task level, only discussing the composite test battery. Here, we attempt to test three measures of WM: one auditory, one visuospatial, and one dual WM task with multimodal input to attend to (auditory and visuospatial) simultaneously (see **Figure 1**).

To our knowledge, none of the existing studies on cognitive aptitude for SLI, whether based on students or working interpreters, have specifically looked at MR (despite being highlighted as a possible predictor by López Gómez et al. (2007), they did not include a rotation task in their test battery). Here we use two different tasks: one where 2D shapes simply need to be rotated in a circle (**Figure 2A**), and another that uses 3D-rendered blocks that must be rotated around the vertical axis only (**Figure 2B**). It is MR in this plane that should be the closest way the sign language input must be rotated while comprehended (Watkins et al., 2018).

We included two linguistic tasks that assess English skills. Initial English vocabulary knowledge was found to predict self-rated ASL proficiency after 1 semester of ASL instruction (Williams et al., 2017). English reading comprehension was also shown to improve during the SLI degree by Stone (2017), and we repeated the same measure here. Summarizing and paraphrasing are known to be an important skills in spoken language interpreting (e.g., Moser-Mercer, 1985; Russo and Pippa, 2004; Russo, 2014). Being able to comprehend and summarize complex spoken English before interpreting it into "chunks" of BSL is also required of SLI students and, thus, we created a task to assess this ability. We also include the MLAT Number Learning task used by Stone (2017) as a measure of phonological encoding, which was predictive of later BSL grades (see also Martinez and Singleton, 2019, who found sign learning and word learning to be highly correlated in hearing non-signers).

As Macnamara et al. (2011) pointed out, cognitive skills do not exist in a vacuum, and there has been a range of studies exploring SLI aptitude in terms of more social factors like disposition and personality (Stauffer and Shaw, 2006; Bontempo et al., 2014). Hence, we also include one personality measure of risk-taking that was predictive of continuation on the SLI degree in Stone (2017), the Barratt Impulsiveness Scale, version 11 (BIS-11; Patton et al., 1995). Specifically, Stone found that SLI students remaining in the degree program were significantly more impulsive, i.e., more likely to take risks than students who were rehoused in a Deaf Studies program (due to choice or poor BSL/interpreting exam performance). Macnamara et al. (2011) also found that a different measure of risk-taking (Behavioral Inhibition System; Carver and White, 1994) differentiated between highly skilled and less-skilled interpreters Lastly, we also used a non-verbal reasoning task as a control measure, which we do not predict will change over time, nor impact BSL or SLI performance.

This preliminary study asks three main research questions: (1) Do any of the cognitive and linguistic assessments predict being selected for, or continuing with, the SLI degree? (2) How do the cognitive and linguistic skills change throughout the SLI degree? (3) Are any of the cognitive or linguistic skills associated with BSL and SLI performance outcomes? In sum, we aim to see if we can replicate previous results in some domains by using identical or similar tasks as in previous longitudinal studies, as well as investigating some new areas (MR, and manipulating the modality of WM tasks). Taken together, these elements could help us get a step closer to understanding which cognitive and linguistic skills indicate the potential of an L2 sign language learner and a successful SLI student.

# Materials and methods

## Participants

Sign language interpreting students ($n$ = 33) were recruited from two undergraduate degree programs: 'MA (Hons) BSL (Interpreting, Translating and Applied Language Studies)' at Heriot–Watt University ($n$ = 23 total) or 'BA (Hons) Interpreting (BSL/English)' at the University of Wolverhampton ($n$ = 10). Two consecutive year groups of Heriot-Watt students were tested (HW1: $n$ = 11, HW2: $n$ = 12; see **Table 1**). Across

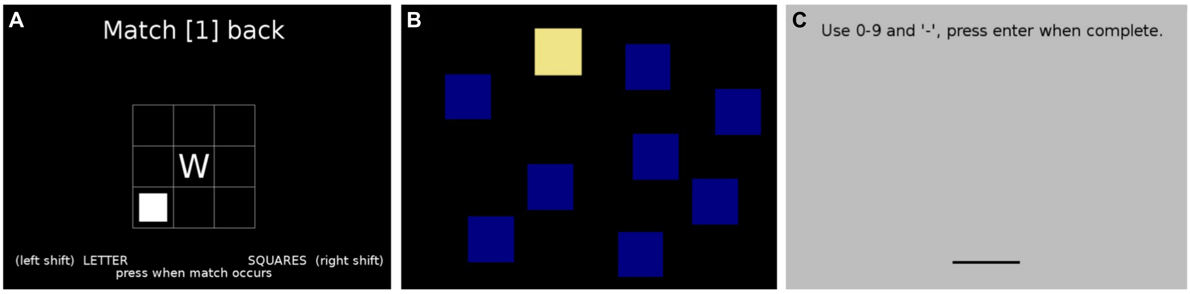


FIGURE 1
Example stills from the working memory tasks used in the study: **(A)** Dual *n*-back task (multimodal working memory, WM); **(B)** Corsi blocks task (visuospatial WM); **(C)** Digit span task (auditory WM).

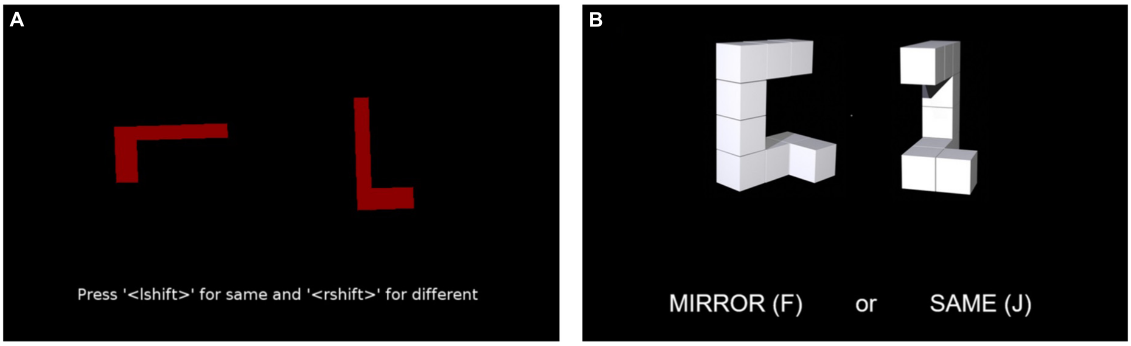


FIGURE 2
Example stills from the two mental rotation (MR) tasks used in the study: **(A)** simple circular 2D shape rotation task showing an example "same" pair rotated 90°; **(B)** 3D-rendered block rotation task around vertical axis only, showing an example "mirror" pair rotated 150°.

all cohorts, three participants were heritage signers of BSL and were, thus, excluded from later analyses. The remaining L2 participants mostly had only limited exposure to BSL before beginning their interpreting program (e.g., introductory courses). A further group of prospective candidates for the first HW cohort (HW0: $n = 19$) were tested at interview but were not selected for entry into the degree program. Therefore, data only exists for this group from session 1.

## Longitudinal study design

Participants were tested on a battery of cognitive and linguistic assessments at four sessions, approximately 1 year apart. Session one was before beginning the program and, thus, for most participants, before critical exposure to BSL had begun. Session two was at the end of the first year of the course, and the third session was at the end of the second year before students began their placement/internship years. The fourth and final session was halfway through this placement year. Due to disruption related to the COVID-19 pandemic (e.g., lack of equipment or suitable space for remote participation at home), as well as students dropping out of their courses or not being interested in further participation at later test sessions, it was not possible to re-test all participants at test sessions two to four. Furthermore, the online testing at later sessions was spread out more than planned compared to pre-pandemic testing, which was carried out in-person on specific dates at the Heriot-Watt and Wolverhampton University campuses.

## Description of test battery

First, the cognitive and linguistic aptitude assessments comprising the predictor variables are described, followed by the BSL and SLI assessments, which make up the outcome variables (see Table 2).

### Predictor variables

#### Working memory tasks

As a measure of multimodal WM, participants completed the Psychology Experiment Building Language (PEBL; Mueller, 2014; Mueller and Piper, 2014) test battery version of the dual *n*-back task (Jaeggi et al., 2008). In the task, participants must simultaneously recall a sequence of letters presented auditorily, as well as the spatial location of a sequence of squares, presented visually on a grid. Participants press a button when

TABLE 1 Demographics of the cohorts of sign language interpreting (SLI) students who took part in the longitudinal study.

| Institution | Heriot-Watt University | | | University of Wolverhampton |
|---|---|---|---|---|
| **Cohort** | **Rejected** | **1st Cohort** | **2nd Cohort** | **Single cohort** |
| Cohort code | HW0 | HW1 | HW2 | WV |
| *N* | 19 | 11 | 12 | 10 |
| Mean age at session 1 (years; months) | 24;2 | 22;8 | 27;1 | 26;3 |
| Mean prior BSL exposure (years; months) | 3;1 | 1;8 | 1;4 | 4;10 |
| Session 1 (pre-course) | In-person | In-person | In-person | In-person |
| Session 2 (end of year 1) | NA | In-person | Online | Online |
| Session 3 (end of year 2) | NA | Online | Online | Online |
| Session 4 (midway year 3) | NA | NA | Online | Online |

TABLE 2 All skills assessed in the longitudinal study and the test/re-test procedure by cohort.

| Skill (assessment) | Session | | | |
|---|---|---|---|---|
| | **Pre-degree** $n = 33$ | **1st Year** $n = 13$ | **2nd Year** $n = 11$ | **3rd Year** $n = 9$ |
| Multimodal WM (working memory; Dual *N*-Back) | All | All | All | HW2, WV |
| Visuospatial WM (Corsi Blocks) | All | All | All | HW2, WV |
| Auditory WM (Digit Span) | HW2, WV | – | HW2, WV | HW2, WV |
| 2D MR (mental rotation; shape rotation) | HW1 | HW1 | All | HW2, WV |
| 3D MR (block rotation) | HW2, WV | HW2, WV | All | HW2, WV |
| Phonological encoding (MLAT number learning) | HW2, WV | – | – | – |
| English comprehension (Kirklees reading) | All | All | All | – |
| Non-verbal reasoning (KBIT-2 matrices) | All | All | All | – |
| Summarizing (TED talk task) | HW2, WV | – | – | – |
| Impulsivity (Barratt Impulsiveness Scale) | – | – | All | HW2, WV |
| BSL sign repetition (copy-sign) | All | – | – | – |
| BSL sentence repetition (BSL-SRT) | NA | – | All | HW2, WV |
| BSL (BSL module grades) | NA | All | All | Placement |
| SLI (BSL to English task) | NA | NA | – | HW2, WV |
| SLI (English to BSL task) | NA | NA | – | HW2, WV |
| SLI (SLI module grades) | NA | NA | HW2, WV | Placement |

the letter or square location matches the letter or square location presented *n* trials ago. The task has one block each of 1-back, 2-back, and 3-back trials. The dependent measure was combined accuracy (average accuracy across both letter-matching and spatial matching).

For visuospatial WM, participants completed the PEBL version of the Corsi block-tapping task (Corsi, 1972; Kessels et al., 2000). In the task, participants must memorize the order, in which a sequence of blocks changes color and then click the blocks in the same order. The sequence gets progressively longer as the task goes on. The dependent measure was the number of correct responses.

As a measure of auditory WM, participants completed the PEBL test battery version of the Digit Span task (Croschere et al., 2012). In this task, participants must remember a sequence of numbers presented auditorily number-by-number, and then type in the sequence of numbers as it was heard. The sequence of numbers gets progressively longer as the task goes on. The dependent measure was the accuracy of responses.

### Mental rotation tasks

At sessions one and two, HW1 participants completed the simple 2D PEBL MR task (Shepard and Metzler, 1988; Berteau-Pavy et al., 2011). The HW2 and WV groups also completed this task at sessions three and four. In this task, participants must decide if two shapes presented side-by-side on the screen are the same or different by mentally rotating them. The dependent measure was a speed-accuracy trade-off score that combines RT and accuracy measures, calculated using the

Balanced Integration Score (Liesefeld et al., 2015; Liesefeld and Janczyk, 2019).

For 3D-MR, participants completed a 3D block rotation task comprising 96 three-dimensional stimuli validated by Ganis and Kievit (2015). The task was created using PsychoPy/Pavlovia (Peirce et al., 2022) and is freely available at https://pavlovia.org/freyawatkins/block_rotation. The task is a measure of MR around the vertical axis, where participants must decide whether two shapes presented side-by-side on the screen are identical or mirror images by mentally rotating them as quickly and accurately as possible. The dependent measure was again a speed-accuracy trade-off score, combining RT and accuracy into a single measure.

### Phonological encoding

At session one, the HW2 and WV groups completed the Number Learning subtest of the MLAT (Carroll and Sapon, 1959; Carroll et al., 2010), which is a measure of "auditory alertness" and phonological encoding. Participants are taught a number system in a made-up language through auditory input and tested by being asked to translate new combinations of numbers from the made-up language back into English numerals. The test features 43 items. The dependent measure was response accuracy.

### Linguistic tasks

As a measure of English reading comprehension, participants completed the revised Kirklees version of the Vernon Warden Reading Test (Warden, 1956; Hedderly, 1996). In the task, participants must complete 42 sentences by selecting the most appropriate word to fill a gap from the five options provided. Participants were given 10 min to complete the task, which was completed using pen and paper at face-to-face testing sessions and using a digitized version at online testing sessions. The dependent measure was test accuracy.

As a measure of summarizing ability, students had to listen to a short presentation (a TED talk on climate change and food, Ebi, 2019) and afterward suggest a title for the presentation and summarize the presentation in five key bullet points. The dependent measure was the accuracy of the summary.

### Non-verbal reasoning

Participants completed the Matrices subtest from the Kaufman Brief Intelligence Test-2 (KBIT-2; Kaufman and Kaufman, 2004). In this task, participants are presented with visual stimuli with a specific rule or relationship, which participants must understand and then select the picture or pattern from the options provided that best fits that relationship or rule. Participants were given 10 min to complete the task, which was completed using pen and paper at face-to-face testing sessions and using a digitized version plus spreadsheet answer key at online testing sessions. The dependent measure was test accuracy.

### Impulsivity

Participants completed the BIS-11 (Patton et al., 1995), a 30-item questionnaire, where they self-rate the frequency of their behavior and preferences regarding impulsivity. The dependent measure was the total score.

## Outcome variables

### British Sign Language performance

All students at session one completed a copy-sign task, which was a measure of BSL reception and production. The task consists of 10 BSL signs and three short BSL sentences, which were presented twice by a Deaf L1 signer and had to be reproduced by the students as accurately as possible. The accuracy of BSL production was coded by a sign language interpreter, with marks for phonological parameters (handshape, movement, location, orientation, and non-manual features) articulated correctly for individual signs, as well as phrasing and prosody for sentences.

At sessions three and four, students were tested on the BSL Sentence Reproduction Test (BSL-SRT; Cormier et al., 2012). The test involves viewing BSL sentences of increasing complexity and reproducing them as accurately as possible. The test is, therefore, an assessment of both BSL comprehension and production. Videos of BSL production were coded for accuracy by an SLI instructor, with one mark for each sentence reproduced correctly.

Module grades from BSL modules were collected from both semesters for the first 2 years of the course. For HW1 and HW2 students, grades included two first-year intensive practical modules in BSL and two second-year modules in Advanced BSL. For WV students, grades were made up of the first-year modules "Intermediate BSL Enhancement for Interpreters A, B, and C" and the second-year modules "Advanced BSL Enhancement for Interpreters A, B, and C"[1]. Third-year grades mostly relate to student placements and are not included in analyses. Grades follow the standard UK university grading system (0–100; whereby most marks fall between the range 40–80, see, e.g., Yorke et al., 2000).

### Sign language interpreting performance

At session four, HW2 and WV participants completed two consecutive interpreting tasks hosted on GoReact (GoReact, 2022). In the first, they had to sequentially (not simultaneously) interpret a four-minute story from BSL into English. The story,

1 Details of the BSL and interpreting modules at the institutions in this study are at the links below. Heriot-Watt University: https://web.archive.org/web/20220124142725/hw.ac.uk/uk/study/undergraduate/british-sign-language-interpreting-translating-and-applied-language.htm University of Wolverhampton: https://web.archive.org/web/20220311152939/wlv.ac.uk/courses/ba-hons-interpreting-british-sign-languageenglish/

signed by an L1 Deaf signer in an informal register, was about a COVID-19 vaccination appointment. In the second task, students interpreted a three-and-a-half-minute instructional video from English into BSL. In the video, a nurse with L1 English explains the procedure for visiting a COVID-19 ward in a hospital, using a more formal register. Students were allowed to pause the video to 'chunk' their interpretation as they saw fit: this 'chunking' skill was also part of the assessment of the interpretation. These tasks were assessed by an SLI educator and graded like university assignments (0–100). The total score for each consecutive interpreting task was calculated based on poise, style, consecutive management, comprehension, conceptual rendition, vocabulary, accuracy, repairs, and an overall mark.

Module grades from second-year interpreting modules were also collected. For HW1 and HW2 students, these comprised the 'Introduction to Translation and Interpreting skills' module, while for WV students, the modules 'Consecutive Interpreting 1 and 2'. Third-year grades mostly relate to student placements and are not included in analyses.

## Ethics approval statement

For the initial cohort (HW0 and HW1), ethical approval was gained from Heriot-Watt University. For the HW2 and WV cohorts, approval was gained from the University of Birmingham Science, Technology, Engineering, and Mathematics Ethical Review Committee (ERN_18-1170). Updated ethical approval was gained for later testing sessions, which took place online due to the COVID-19 pandemic. All subjects gave written informed consent in accordance with the Declaration of Helsinki, as well as video consent for tasks where participants were filmed while signing.

## Test procedure

Within each testing session, the order of assessments was randomized. This was dependent in part on the availability of researchers to run an assessment at any given time and on computer availability for online testing.

## Statistical analysis

### Analysis plan

Our exploratory analyses are divided into three sections. First, we use stepwise backward logistic regression to determine whether any assessments were predictive of (1) being selected for, and (2) continuing with the SLI degree. The second analysis examines changes in the linguistic and cognitive assessments over time, looking at each predictor in turn. Here we use linear mixed models with random effects structure for participants per task, with initial BSL proficiency as a covariate. Finally, the third analysis looks at correlations between the linguistic/cognitive assessments and (1) BSL performance and (2) SLI performance (grades and BSL/SLI tasks). Here, we begin by examining whether there are any relationships between the predictors at the pre-degree initial testing session and later outcome variables, and then looking at any relationships when assessments are repeated at later testing points. We calculate $r^2$ values and also fit linear mixed models with initial BSL proficiency as a covariate.

### Data availability and reproducibility

We report all data exclusions (if any), all manipulations, and all measures in the study, and we attempt to follow JARS (Kazak, 2018). This study's design and its analyses were not pre-registered. In line with standards of reproducible research, the scripts, and data (excluding video data and possibly identifying variables, such as age) are made available with this publication and can be retrieved on the following publicly accessible repository: https://osf.io/kjctg. We used R version 4.0.5 (R Core Team, 2021) plus the packages {`lme4`} v1.1.27.1 (Bates et al., 2015), {`sjPlot`} v2.8.10 (Lüdecke, 2021) and {`blorr`} v0.3.0 (Hebbali, 2020) for the regression/mixed-effects model analyses and output reported below, plus {`effsize`} v0.8.1 (Torchiano, 2020) to calculate effect sizes. For data processing and visualization, we used the package {`tidyverse`} v1.3.1 (Wickham et al., 2019), for file organization {`here`} v1.01 (Müller, 2020), and for plotting details we used {`scales`} v1.1.1 (Wickham and Seidel, 2020), {`PupillometryR`} v0.0.3 (Forbes, 2020), {`sdamr`} v0.1.0 (Speekenbrink, 2021), {`plotrix`} v3.8.1 (Lemon, 2006), and {`patchwork`} v1.1.1 (Pedersen, 2020).

### Attrition and missing data

Our longitudinal study was subject to high levels of attrition over time, for a combination of known and unforeseen reasons. The aforementioned high drop-out rate from SLI degree programs was a known factor that we expected would greatly reduce participation at later sessions. Missing data from these participants could be considered 'missing-at-random', where degree program drop-out relates to poor grades or difficulty with the content of the program. However, the outbreak of the COVID-19 pandemic introduced a large number of reasons for data to be 'missing-not-at-random', which we could not account for with auxiliary variables (e.g., socioeconomic background, income-to-needs ratio, participant disability, parental education). For example, the pandemic necessitated online testing at sessions 2, 3, and 4. This was not equally accessible to all participants, due to differences in access to equipment, technological knowledge, time, space to participate remotely, etc. Furthermore, pandemic-related illness also prevented some participants from repeating tasks at specific time points. While multiple imputation of missing data is possible, even when data are missing-not-at-random for reasons like these (see, e.g., Madley-Dowd et al., 2019), this approach is only considered appropriate when auxiliary variables that may have correlated with missingness are also present in the dataset. Since we did not collect initial data on these factors, imputing missing data would not have produced less biased estimates.

# Results

## Predictors of selection and remaining in sign language interpreting degree program

### Predictors of selection

The first sub-analysis examines whether any of the cognitive and linguistic assessments at session one (pre-degree) were predictive of being selected for the degree program, using data from the HW1 cohort, plus the candidates who were assessed at the interview but not selected (HW0). We fit a backward stepwise logistic regression model to identify possible predictors of the binary outcome variable "selected" (0, 1) out of the following predictor variables: multimodal WM, visuospatial WM, non-verbal reasoning, English vocabulary, 2D-MR, and initial BSL self-rating. At each step, variables were chosen based on $p$-values, and a default $p$-value threshold for backward stepwise regression of 0.1 was used to set a limit on the total number of variables included in the final model. The stepwise regression reduced the predictors to just the 2D-MR score ($z$ = 1.78, $p$ = 0.075) and BSL self-rating ($z$ = 1.91, $p$ = 0.056), whereby higher 2D-MR scores and higher BSL self-ratings, respectively, were both significant predictors of being selected for the degree. While we did not have enough data from the copy-sign task coded to include in the model, self-rated BSL proficiency and copy-sign task scores were significantly positively correlated ($r^2$ = 0.42, $t$ = 3.16, $p$ = 0.007).

### Predictors of continuation

Our second sub-analysis looks at students across the three cohorts who were selected for the degree program, i.e., excluding those who were not successful in gaining a place at the interview. Here, we ask whether any of the initial assessments carried out pre-degree predicted whether students were continuing with the degree program at the time of writing (in their final or penultimate year). Again, we fit a backward stepwise logistic regression model to identify possible predictors of the binary outcome variable "continuing" (0, 1) out of the following predictor variables: multimodal WM, visuospatial WM, non-verbal reasoning, English vocabulary, and initial BSL self-rating. At each step, variables were chosen based on $p$-values, and a default $p$-value threshold for backward stepwise regression of 0.1 was used to set a limit on the total number of variables included in the final model. The stepwise regression reduced the predictors of continuing with the SLI degree to just visuospatial WM ($z$ = –1.77, $p$ = 0.078), whereby a higher visuospatial WM score significantly predicted continuing on the degree. As an additional analysis, we also modeled impulsivity at the end of the second year, but this did not predict continuation in the degree.

## Changes in cognitive and linguistic skills during sign language interpreting program

In our second set of analyses, we look at all the cognitive and linguistic assessments in turn and examine their change over time, as students progress through the SLI program. All linear models have initial BSL skill as a covariate and random effects for participants, and use a standard $p$-value threshold for linear models of 0.05. Models of English comprehension also included age at the initial testing session as a covariate.

### Working memory tasks over time

Multimodal WM (Dual N-Back) was significantly improved after 2 years of study compared to pre-degree ($t$ = 2.32, $p$ = 0.02, $d$ = 0.56; **Figure 3A**). However, this improvement did not hold in the final session ($t$ = 0.12, $p$ = 0.91) compared to pre-degree.

Performance on the visuospatial WM task (Corsi Blocks) was significantly improved after 1 year of study compared to pre-degree ($t$ = 2.01; $p$ = 0.044, $d$ = 0.29; **Figure 3B**). However, this improvement did not hold for the latter two sessions (second year: $t$ = –0.06, $p$ = 0.95; third year: $t$ = 1.52, $p$ = 0.13).

Auditory WM performance (Digit Span) was not significantly improved by the second year compared to pre-degree ($t$ = 0.53, $p$ = 0.59), but third year accuracy was significantly higher than pre-degree ($t$ = 2.72, $p$ = 0.007, $d$ = 1.57; **Figure 3C**).

### Mental rotation tasks over time

Performance on the 2D shape rotation task was significantly improved after 1 year of study compared to pre-degree ($t$ = 2.71, $p$ = 0.007)[2]. Interestingly, the covariate initial BSL skill played a negative role in predicting 2D-MR performance overall ($t$ = –2.21, $p$ = 0.028). Reaction times were significantly faster than pre-degree at all subsequent sessions (first year: $t$ = –3.9, $p$ < 0.001, $d$ = 1.07; second year: $t$ = –2.88, $p$ = 0.004; third-year: $t$ = –3.32, $p$ = 0.001). On the 3D block rotation task, speed-accuracy trade-off scores were significantly higher than pre-degree at all subsequent sessions (first year: $t$ = 2.52, $p$ = 0.012, $d$ = 1.32; second year: $t$ = 4.6, $p$ < 0.001, $d$ = 0.91; third year: $t$ = 5.31, $p$ < 0.001, $d$ = 1.68; **Figure 3D**). Likewise, reaction times on the 3D-MR task were significantly faster than pre-degree at all subsequent sessions (first year: $t$ = –2.2, $p$ = 0.028, $d$ = 1.97; second-year:

2 Effect sizes could only be calculated for 2D-MR where enough participants completed the task at both of the sessions being compared.

$t = -5.3$, $p < 0.001$, $d = 1.33$; third year: $t = -5.69$, $p < 0.001$, $d = 2.53$), although accuracy alone was only significantly improved at the final session ($t = -2.16$, $p = 0.031$, $d = 0.57$).

### Linguistic and other assessments over time

English reading comprehension (Kirklees) showed no effect of testing session when comparing pre-degree accuracy to first-year performance ($t = -1.19$, $p = 0.24$) or second-year performance ($t = 1.38$, $p = 0.17$). Our control measure, non-verbal reasoning (KBIT-2 Matrices), also showed no effect of session when comparing pre-degree accuracy with first-year performance ($t = -1.28$, $p = 0.20$) or second-year performance ($t = 0.5$, $p = 0.62$). Impulsiveness (BIS) was only tested during the second and third years but was significantly reduced at the final testing session compared to the penultimate session ($t = -2.39$, $p = 0.017$, $d = 0.28$), though the effect size was small. Due to time constraints on in-person testing and limited data from online testing sessions, the tasks assessing phonological encoding and summarizing were only conducted at one session each, and, therefore, no change-over-time analyses were conducted.

## Predictors of British Sign Language and sign language interpreting performance

Our final set of analyses examines whether any of the cognitive and linguistic assessments were associated with (1) BSL and (2) SLI performance. Firstly, we look at whether any assessments were related to BSL measures, such as grades in BSL modules and BSL Sentence Reproduction Test scores. Due to the high level of attrition across the longitudinal study, we do not attempt to fit a large mixed model with all predictors for outcome variables at the final session. Instead, we report correlations and individual regression analyses, modeling BSL and SLI measures as a function of predictor assessments, with initial BSL proficiency as a covariate. Models of English comprehension also include age at the initial testing session as a covariate.

### Working memory tasks and British Sign Language performance

As a reminder of our hypotheses: we did not predict that the WM assessments would have an impact on any BSL outcomes, other than visuospatial WM. There was no relationship between initial multimodal WM (Dual N-Back) and second year BSL grades ($r^2 = 0.006$), nor did multimodal WM relate to third-year BSL-SRT scores ($r^2 = 0.002$). The relationship between third-year multimodal WM skill and SRT scores was not significant ($r^2 = 0.12$, $t = 0.83$, $p = 0.44$). We found no relationship between initial visuospatial WM (Corsi Blocks) and second-year BSL grades ($r^2 < 0.001$), nor with third-year BSL-SRT scores ($r^2 = 0.10$). However, third-year SRT scores were significantly positively associated with visuospatial WM skill in second-year ($r^2 = 0.609$, $t = 2.73$, $p = 0.041$; **Figure 4A**), but the positive correlation with third-year WM was not significant ($r^2 = 0.301$, $t = 1.55$, $p = 0.17$; **Figure 4B**). In terms of auditory WM, initial digit span scores were not associated with first ($r^2 = 0.12$) or second-year BSL grades ($r^2 = 0.14$), nor with third-year BSL-SRT scores ($r^2 = 0.001$).

### Mental rotation tasks and British Sign Language performance

There was no relationship between performance on the initial 2D rotation task and second-year BSL grades ($r^2 = 0.001$). The relationships between second-year 2D-MR scores and second-year BSL grades ($r^2 = 0.27$, $t = 1.64$, $p = 0.14$), as well as between third-year rotation scores and third-year BSL-SRT scores ($r^2 = 0.19$, $t = 1.5$, $p = 0.18$), showed moderate positive correlations, but these were also not significant.

Likewise, for 3D-MR, there was no relationship between initial 3D rotation skill and second-year BSL grades ($r^2 < 0.001$). Initial 3D-MR scores were positively correlated with third-year BSL-SRT scores, but this correlation was not significantly different from zero ($r^2 = 0.37$; $t = 1.81$, $p = 0.12$; **Figure 5A**). Second-year 3D-MR and second-year BSL grades were also strongly correlated, but the effect was marginally insignificant ($r^2 = 0.39$, $t = 2.21$, $p = 0.054$; **Figure 5B**). Third-year 3D rotation scores were unrelated to third-year BSL-SRT scores ($r^2 = 0.12$).

### Linguistic and other assessments and British Sign Language performance

There was a significant positive relationship between initial English reading comprehension (Kirklees) and first-year BSL grades ($r^2 = 0.19$, $t = 2.90$, $p = 0.008$; **Figure 6A**), but not with subsequent BSL grades ($r^2 = 0.02$). The relationship between initial reading comprehension and third-year BSL-SRT score showed a moderate positive correlation, but this was not significant ($r^2 = 0.237$, $t = 1.56$, $p = 0.17$; **Figure 6B**). In terms of the summarizing task, as predicted, there was no impact on first- ($r^2 = 0.002$) or second-year BSL grades ($r^2 = -0.06$), nor was there a relationship with third-year BSL-SRT score ($r^2 = 0.01$).

We found no relationship between initial phonological encoding ability (MLAT Number Learning) and second-year BSL grades ($r^2 = 0.033$), nor was there a relationship with third-year BSL-SRT score ($r^2 < 0.001$). There was no association between impulsivity (BIS) and second-year BSL grades ($r^2 = 0.009$). Impulsivity had a slight negative correlation with third-year BSL-SRT scores, but this relationship was not significant ($r^2 = -0.27$, $t = -1.45$, $p = 0.19$). There was no relationship between our control measure (non-verbal reasoning; KBIT-2 Matrices) and second-year BSL grades ($r^2 = 0.001$). Non-verbal reasoning also did not correlate with third-year BSL-SRT scores ($r^2 = 0.004$).

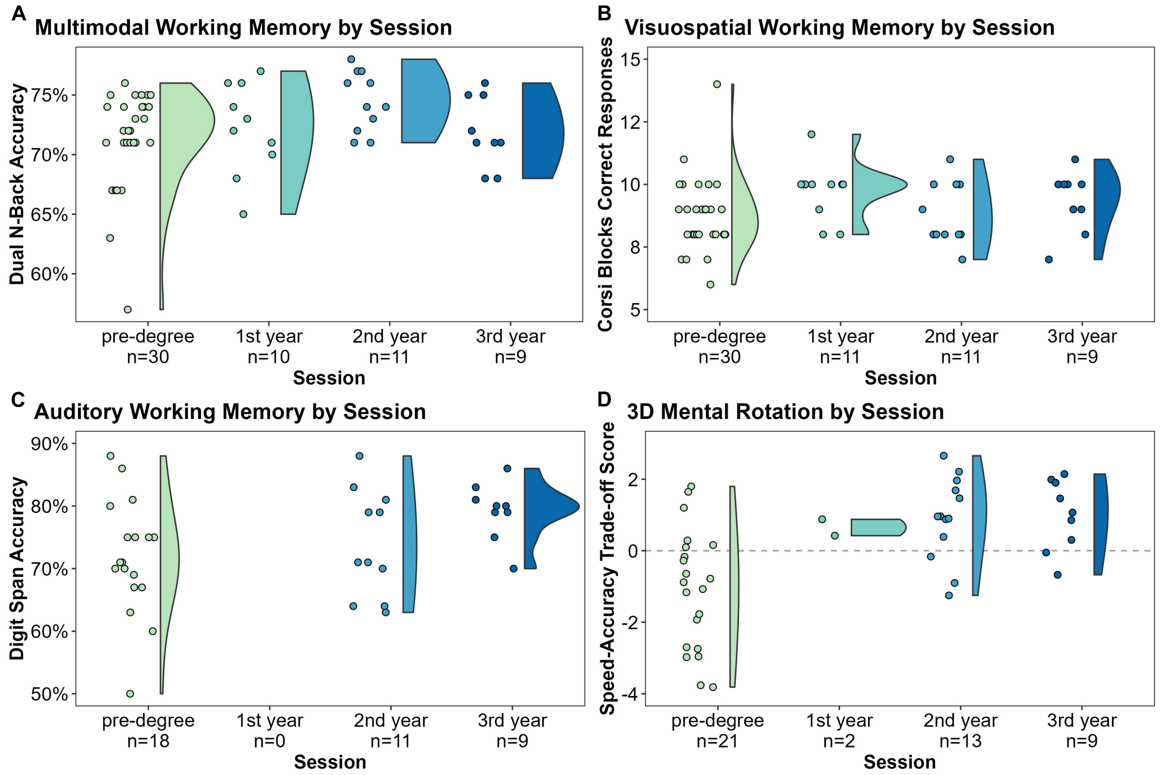


FIGURE 3
Changes in sign language interpreting student performance on four cognitive assessments over time: **(A)** multimodal working memory (WM) was significantly improved after 2 years of study compared to pre-degree ($t$ = 2.32, $p$ = 0.02, $d$ = 0.56); **(B)** visuospatial WM was significantly improved after 1 year of study compared to pre-degree ($t$ = 2.01; $p$ = 0.044, $d$ = 0.29); **(C)** auditory WM was significantly improved after 3 years of study compared to pre-degree ($t$ = 2.72, $p$ = 0.007, $d$ = 1.57); **(D)** 3D mental rotation (MR) was significantly improved compared to pre-degree at all subsequent sessions (vs. first year: $t$ = 2.51, $p$ = 0.012, $d$ = 1.32; vs. second-year: $t$ = 4.6, $p$ < 0.001, $d$ = 0.91; vs. third-year: $t$ = 5.31, $p$ < 0.001, $d$ = 1.68).

Now we turn to look at the relationships between cognitive and linguistic assessments and measures of SLI performance, such as SLI module grades and the two final consecutive SLI tasks.

## Working memory tasks and sign language interpreting performance

There was no significant relationship between initial multimodal WM scores and second-year interpreting grades ($r^2$ = 0.11), nor with performance on the third-year English-to-BSL consecutive interpreting task ($r^2$ = 0.12). This correlation was slightly stronger for third-year multimodal WM scores, but, again, not significantly so ($r^2$ = 0.16, $t$ = 0.7, $p$ = 0.51). Initial multimodal WM did not affect scores on the consecutive interpreting task from BSL to English ($r^2$ = 0.06).

In terms of visuospatial WM, there was no link between initial performance on the Corsi Blocks task and second-year interpreting grades ($r^2$ = 0.008), nor did a relationship emerge with visuospatial WM at later testing sessions. There was a stronger yet insignificant correlation between initial visuospatial WM and scores on the third-year English-to-BSL consecutive interpreting task ($r^2$ = 0.29, $t$ = 1.27, $p$ = 0.25), and for second-year visuospatial WM, this relationship was only marginally insignificant ($r^2$ = 0.57, $t$ = 2.48, $p$ = 0.056; **Figure 7A**). Second-year visuospatial WM was also positively correlated with performance in the third-year consecutive interpreting task from BSL to English, but, again, the correlation was insignificant ($r^2$ = 0.46, $t$ = 1.82, $p$ = 0.14).

There was a promising positive correlation between initial auditory WM (Digit Span) scores and SLI grades in the second year, which was marginally insignificant ($r^2$ = 0.24 $t$ = 1.96, $p$ = 0.076; **Figure 7B**). Auditory WM at the final testing session was not related to the final English-to-BSL consecutive interpreting task ($r^2$ = 0.12), nor the BSL-to-English task ($r^2$ = 0.03).

## Mental rotation tasks and sign language interpreting performance

There was no relationship between initial 2D-MR skill and second-year SLI grades ($r^2$ = 0.038). We found stronger correlations between second-year SLI grades and 2D-MR skills

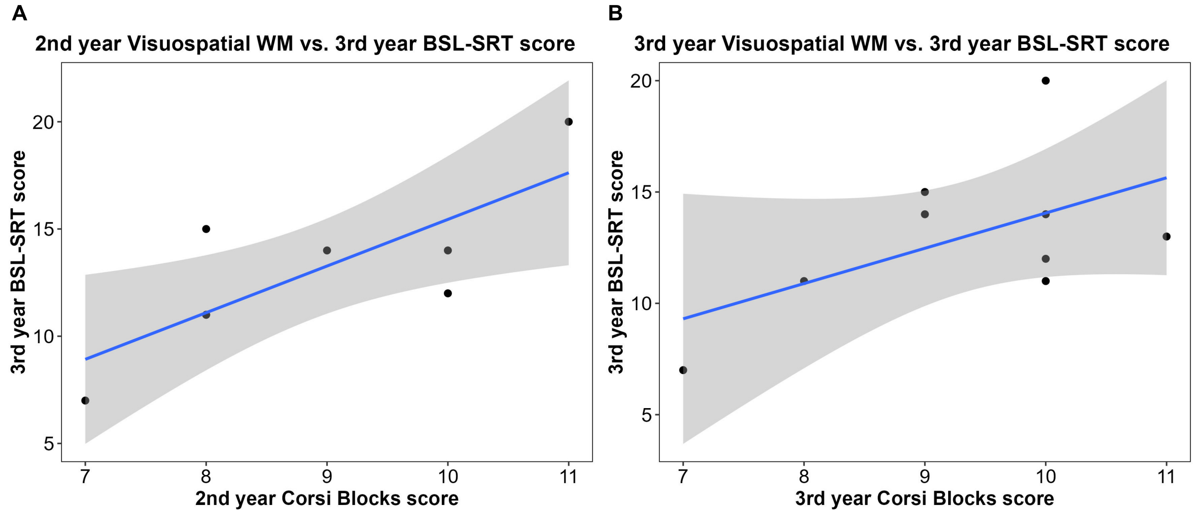


FIGURE 4
Correlations between sign language interpreting (SLI) student performance on working memory tasks and British Sign Language (BSL) measures: **(A)** second-year visuospatial working memory (WM) was a significant predictor of third-year BSL-SRT scores ($n$ = 7; $r^2$ = 0.609, $t$ = 2.73, $p$ = 0.041); **(B)** third-year visuospatial WM was positively correlated with third-year BSL-SRT scores, but this relationship was insignificant ($n$ = 9; $r^2$ = 0.301, $t$ = 1.55, $p$ = 0.17).

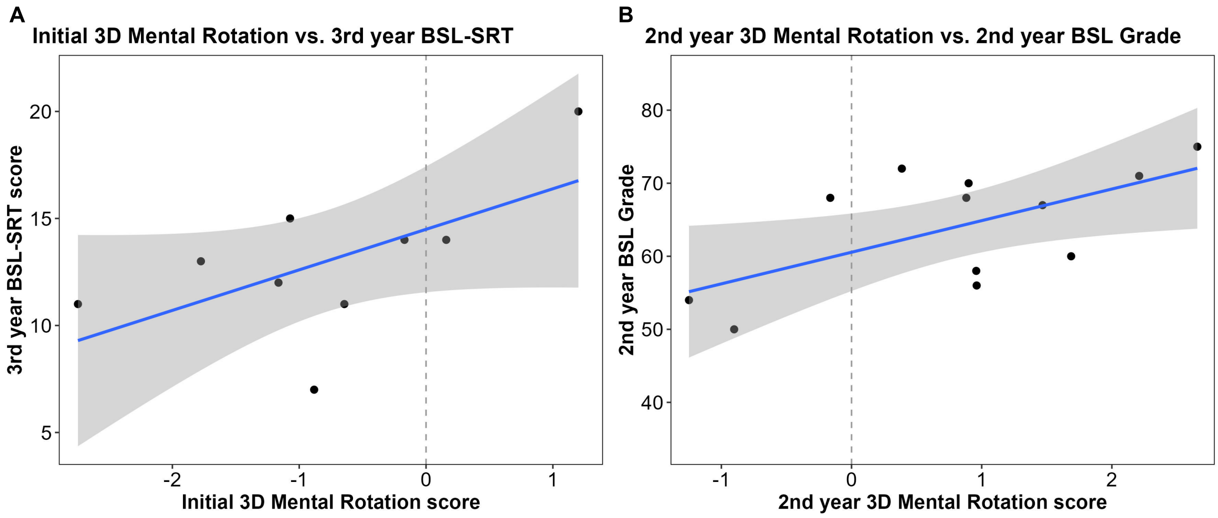


FIGURE 5
Correlations between sign language interpreting (SLI) student performance on mental rotation (MR) tasks and British Sign Language (BSL) measures: **(A)** pre-degree 3D-MR skill was positively correlated with third-year BSL-SRT scores, but this relationship was not significant ($n$ = 9; $r^2$ = 0.37; $t$ = 1.81, $p$ = 0.12); **(B)** second-year 3D-MR was positively correlated with second-year BSL grades, but this relationship was marginally insignificant ($n$ = 12; $r^2$ = 0.39, $t$ = 2.21, $p$ = 0.054).

in both second year ($r^2$ = 0.24, $t$ = 1.64, $p$ = 0.14) and third-year ($r^2$ = 0.39, $t$ = 2.91, $p$ = 0.027), the latter was statistically significant. For the English-to-BSL consecutive interpreting task, there were small positive correlations with second-year ($r^2$ = 0.2) and third-year 2D-MR ($r^2$ = 0.18), but these were not significant. However, for the third-year BSL-to-English interpreting task, the relationship with 2D-MR was stronger: second-year 2D-MR skill was a significant predictor ($r^2$ = 0.6, $t$ = 2.95, $p$ = 0.042; Figure 8A) while third-year 2D-MR skill was a marginally insignificant predictor ($r^2$ = 0.31, $t$ = 2.11, $p$ = 0.088; Figure 8B).

For 3D-MR, there was a moderate yet insignificant positive correlation between initial rotation skill and second-year interpreting grades ($r^2$ = 0.24). This correlation became stronger over time (vs. second-year 3D rotation: $r^2$ = 0.31; vs. third-year 3D rotation: $r^2$ = 0.54, $t$ = 2.85, $p$ = 0.029), the latter relationship

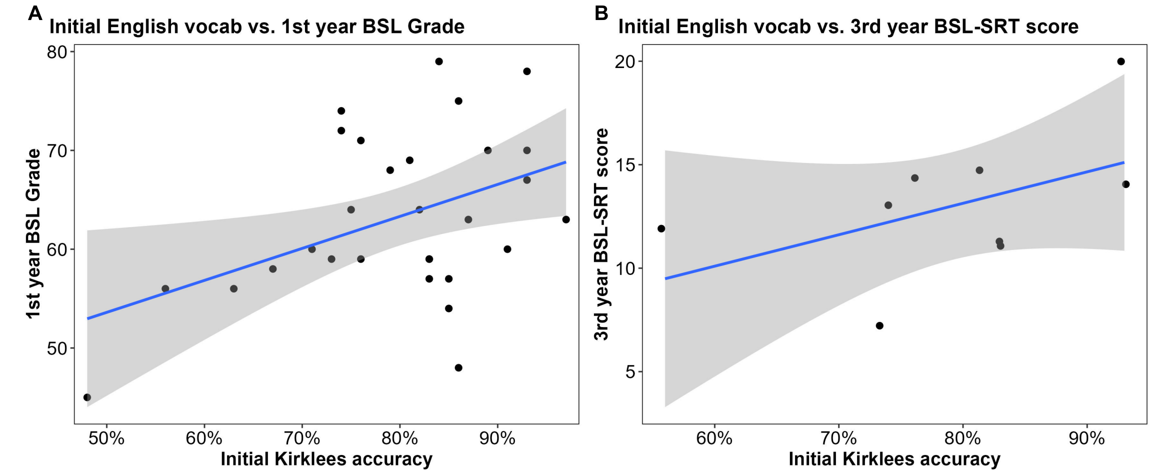


FIGURE 6
Correlations between initial sign language interpreting (SLI) student performance on English reading comprehension and later British Sign Language (BSL) measures: **(A)** pre-degree English comprehension was a significant predictor of first-year BSL grades ($n$ = 29; $r^2$ = 0.19, $t$ = 2.90, $p$ = 0.008); **(B)** pre-degree English comprehension was moderately positively correlated with third-year BSL-SRT scores, but this relationship was not significant ($n$ = 9; $r^2$ = 0.237, $t$ = 1.56, $p$ = 0.17).

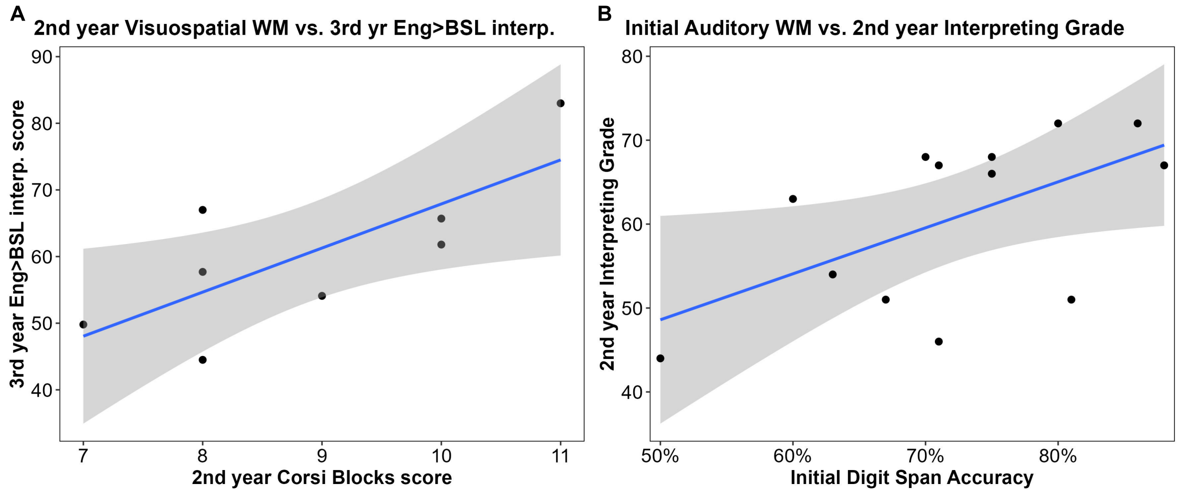


FIGURE 7
Correlations between sign language interpreting (SLI) student performance on working memory (WM) tasks and SLI measures: **(A)** Second-year visuospatial WM skill was positively correlated with performance on the third-year English-to- British Sign Language (BSL) interpreting task, however, this relationship was marginally insignificant (n = 8; $r^2$ = 0.57, $t$ = 2.48, $p$ = 0.056); **(B)** pre-degree auditory WM was correlated with 2nd-year SLI grades but this relationship was marginally insignificant ($n$ = 13; $r^2$ = 0.24; $t$ = 1.96, $p$ = 0.076).

being significant. Initial 3D-MR also had a moderate but insignificant positive correlation with third-year English-to-BSL consecutive interpreting performance ($r^2$ = 0.27, $t$ = 1.32, $p$ = 0.24; Figure 8C), although there was no correlation with later 3D-MR scores. Initial 3D-MR skill was also positively correlated with third-year consecutive interpreting from BSL to English, and this relationship was marginally insignificant ($r^2$ = 0.48, $t$ = 2.004, $p$ = 0.101; Figure 8D). However, this correlation got weaker over time (vs. second-year 3D rotation: $r^2$ = 0.29; vs. third-year 3D rotation: $r^2$ = 0.16).

## Linguistic and other assessments and sign language interpreting performance

There was no relationship between English sentence reading (Kirklees) at any time point and SLI grades, or with either of the consecutive SLI tasks. There was also no link between the pre-degree summarizing task and second-year SLI grades ($r^2$ = 0.002), nor with either interpreting task.

We also found no significant relationship between non-verbal reasoning (KBIT-2 Matrices) and any SLI measures. There was no relationship between impulsivity (BIS) and

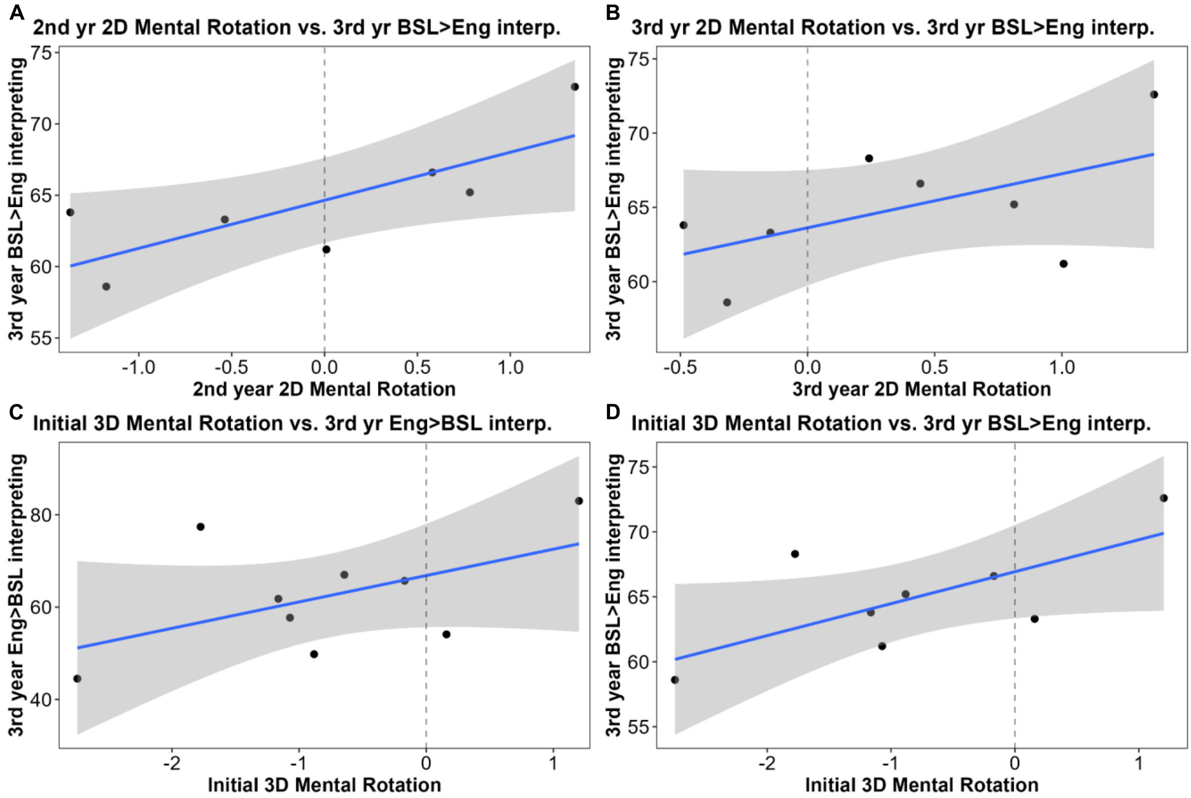


FIGURE 8
Correlations between sign language interpreting (SLI) student performance on mental rotation (MR) tasks and SLI measures: **(A)** second-year 2D-MR was a significant predictor of scores on the third-year British Sign Language (BSL)-to-English interpreting task ($n$ = 7, $r^2$ = 0.6, $t$ = 2.95, $p$ = 0.042); **(B)** third-year 2D-MR was correlated with scores on the third-year BSL-to-English interpreting task, but this relationship was marginally insignificant ($n$ = 8, $r^2$ = 0.31, $t$ = 2.11, $p$ = 0.088); **(C)** pre-degree 3D-MR was positively correlated with scores on the third-year English-to-BSL interpreting task, but this relationship was not significant ($n$ = 9, $r^2$ = 0.27, $t$ = 1.32, $p$ = 0.24); **(D)** pre-degree 3D-MR was correlated with scores on the third-year BSL-to-English interpreting task, but this relationship was marginally insignificant ($n$ = 8, $r^2$ = 0.48, $t$ = 2.004, $p$ = 0.101).

SLI grades. There was a slight negative correlation between impulsivity and English-to-BSL consecutive interpreting, as well as between impulsivity and the consecutive interpreting task from BSL to English ($r^2$ = −0.27), however, these were not significant.

### Correlations among measures of British Sign Language and sign language interpreting performance

Second-year SLI grades were significantly correlated with both first-year BSL grades ($r^2$ = 0.68, $t$ = 7.21, $p$ < 0.001) and second-year BSL grades ($r^2$ = 0.69, $t$ = 6.79, $p$ < 0.001). The initial copy-sign task was a marginally insignificant predictor of first-year BSL grades ($r^2$ = .46, $t$ = 2.25, $p$ = 0.054), but not second-year BSL grades ($r^2$ = 0.21, $t$ = 0.84, $p$ = 0.43). Interestingly, the initial copy-sign task had a stronger correlation with SLI grades in the second year ($r^2$ = 0.36, $t$ = 2.08, $p$ = 0.076) than with second-year BSL grades, but again this was marginally insignificant. Performance on the third-year BSL-SRT task was significantly correlated with first-year BSL grades ($r^2$ = 0.66, $t$ = 3.37, $p$ = 0.015) and strongly correlated with second-year BSL grades ($r^2$ = 0.53, $t$ = 2.25, $p$ = 0.074), which was a marginally insignificant predictor. The two consecutive SLI tasks (BSL-to-English and English-to-BSL) were also significantly correlated with each other ($r^2$ = 0.79, $t$ = 4.14, $p$ = 0.009).

## Discussion

### Summary of key findings

In this exploratory study, we saw several significant relationships between cognitive and linguistic skills and SLI degree program outcomes. Firstly, we found that 2D-MR skill and initial self-rated BSL proficiency were significant predictors of selection for the SLI degree, whereas visuospatial WM predicted the continuation of the course. Next, we examined the impact of the SLI degree program on cognitive and linguistic skills over time, by first collecting baseline measures of these skills and repeating testing at three further sessions. We found improvements in multimodal WM by the end of the second year of the degree, in visuospatial WM by the end of the first year, and in auditory WM by the final testing session in the third year. While multimodal and visuospatial WM did not remain at these improved levels at subsequent sessions, both 2D- and 3D-MR skills were improved by the first year of the degree and consistently remained at these higher levels throughout our longitudinal study. In terms of cognitive and linguistic predictors of later BSL and SLI task performance, there were several significant and marginally insignificant results of note, despite our small sample size. First-year BSL grades were significantly predicted by pre-degree English comprehension; second-year BSL grades were strongly correlated with second-year 3D-MR (marginally insignificant), and third-year BSL-SRT scores were significantly predicted by second-year visuospatial WM. Second-year visuospatial WM was also strongly correlated with scores on the English-to-BSL interpreting task, and pre-degree auditory WM was strongly correlated with second-year SLI grades (both marginally insignificant). In terms of the third-year BSL-to-English interpreting task, 3D-MR was a significant or marginally insignificant predictor at three different testing sessions (pre-degree, second year, and third year). We now turn to consider some issues with data collection and attrition, and then move on to a detailed discussion of each of our three research questions and their related analyses in turn.

## Issues with data collection and attrition

The various effects of the COVID-19 pandemic had a considerable impact on our exploratory study, mostly in terms of student withdrawals from the degree program and the difficulties of re-testing students online at later sessions, making it more of a preliminary investigation. In particular, the earliest cohort (HW1), for whom the practical placement year fell during the first year of the pandemic, was affected heavily by withdrawals. Only a minority remained in the SLI degree program by the final year (just three of the original 12, i.e., 25%; one student joined the year group below). Some of those who withdrew continued on a BSL-only program, while others switched to unrelated degree courses or left university altogether. Anecdotal evidence from program instructors and students themselves suggests that the main reason for the high-withdrawal rate in this cohort was indeed the various impacts of the pandemic, which our statistical models had no way to account for without further demographic auxiliary variables. In particular, having to do interpreting placements remotely seemed to be isolating and discouraging for students, and not the immersive experience it might have been in-person. As a result, it is likely that capable and otherwise potentially successful students (particularly in this cohort) ended up withdrawing from their SLI program. However, it should be noted that most students in the other two cohorts remained in their programs. We believe our data still offer valuable insights about SLI aptitude given the range of assessments tested across multiple sessions, given the present lack of longitudinal work with baseline measures in the literature.

## Predictors of selection and remaining in sign language interpreting degree program

In our initial analyses, we saw some limited evidence of initial pre-degree assessments predicting whether students were either selected for or continued with, their SLI degree program. For the selection analysis, the best predictors were initial self-rated BSL proficiency and the 2D-MR task. Unsurprisingly, those students with some initial signing proficiency were more likely to be selected ahead of those with no knowledge of BSL and deaf culture. However, this could also be an indicator of confidence, and there may be an unconscious selection bias for students who appear more confident. This result also highlights that it is difficult to test SLI aptitude in university students from a complete baseline of no BSL exposure at all, since many are unlikely to commit to a degree without some prior signing experience. Furthermore, in recent years there have been greater opportunities to start learning BSL in secondary schools than has historically been the case. Although timing and funding constraints meant we were not able to code enough of the copy-sign data to include it as a predictor in the selection model, the data, available suggest that scores on the task correlated significantly with applicants' BSL proficiency self-ratings. While our copy-sign task featured real BSL signs, many of our participants would not yet have been familiar with all the signs used. In this sense, it is similar to the nonsense sign repetition tasks used by López Gómez et al. (2007) and Stone (2017), which also involved phonological encoding and perceptuo-motor skills and were found to be good predictors of later success in their cohorts. The 2D-MR task was also a good predictor of selection, and this is an interesting result given other strong correlations between initial 3D-MR performance and later outcome measures. However, our selection analysis was conducted on just two cohorts (HW0 and HW1) and only five assessments, mostly due to time constraints at the interview stage (latter cohorts were tested during the first week of term, which meant we could test more assessments in a less stressful environment for participants). Future studies could aim to measure other skills at the initial interview stage, which could not be included here due to practical constraints. In particular, 3D-MR and auditory WM would be good candidates, since we found evidence that pre-degree performance in both of these domains in our other cohorts was strongly correlated with third-year SLI performance and SLI grades, respectively. This also suggests that an intervention study that targets improving these general cognitive skills before SLI specialization might be instructive. Lastly, it should be reiterated that SLI program instructors did not have access to the data from the initial assessment session when deciding whether to accept applicants to their degree programs.

In the continuation analysis, there was a significant relationship between pre-degree visuospatial WM and remaining on the SLI degree, whereby higher visuospatial WM scores were associated with continuation. One interpretation of this result is that the cognitive demands of signing and interpreting in the new visuospatial modality are possibly a factor that (consciously or unconsciously) makes students more likely to withdraw from the program (see, e.g., Grbić, 2009). Due to the high withdrawal rate in one specific cohort, it was not possible to include a MR task in the selection model since different cohorts did different rotation tasks in the first session. However, it would be interesting to see whether other cognitive tasks involving visuospatial cognition are also associated with program drop-out, such as the copy-sign task. In terms of impulsivity, we did not replicate the result seen by Stone (2017), whereby the BIS predicted continuation on the SLI degree vs. switching to a Deaf Studies course. Due to testing session time constraints, we only introduced the BIS from session 3 onward, where all testing was already online due to the pandemic, but ideally, we would have also taken a baseline measure of risk-taking. It is quite likely that our participants' usual risk aversion strategies and levels of impulsiveness were inhibited or changed by the ongoing pandemic. The potential for impulsiveness to impact learning behaviors (e.g., having the confidence to attend deaf social events to practice BSL, etc.) was greatly restricted due to pandemic-related safety measures. In future larger studies that follow students through to graduation and beyond, it would be interesting to see whether specific cognitive and linguistic skills are associated with continuation or drop-out at particular points in time; for example, during placements, or once students start interpreting modules.

## Changes in cognitive and linguistic skills during sign language interpreting program

In terms of changes in cognitive and linguistic skills throughout the degree, there was evidence of improvement in several domains. All three WM tasks (multimodal, visuospatial, and auditory) showed some signs of improvement across testing sessions, although performance did not remain at this higher level. Visuospatial WM (Corsi Blocks) and multimodal WM (Dual N-Back) were improved by timepoints two and three, respectively, but these changes did not hold to the final session, nor was there any further improvement. These results are harder to interpret, but it could be that these regressions are related to reduced opportunities to practice BSL and SLI skills at certain points in the degree program. This is likely to have been the case at later sessions due to the effects of the COVID-19 pandemic. Alternatively, these regressions may be explained by the varying demands of the SLI degree program tapping into different aspects of WM more frequently at different time points during the course. Auditory WM (Digit Span) was only at a higher level at the final testing session, midway through the placement year, suggesting there may be potential for further improvement beyond our study yet within the SLI degree. Further testing through to degree completion could be instructive here, as most of our predictions regarding WM were related to SLI, and not BSL learning. In the first 2 years of the SLI program, the focus is mostly on acquiring BSL, where there is a greater emphasis on visuospatial skills, before beginning to interpret. Since the students do much more SLI in their placement year and final year, we would expect the greater potential for this to feedback into WM skills only toward the end of the degree, and beyond during professional practice.

As hypothesized, MR ability in SLI students improved over time, which fits with a wide body of literature on improved visuospatial cognition through sign language use (e.g., McKee, 1987; Talbot and Haude, 1993; Emmorey, 1998; Emmorey et al., 1998; Keehner and Gathercole, 2007; Kubicek and Quandt, 2021). In particular, the improvements on the 3D-MR task between the pre-degree and the final session had the strongest effect size across the entire longitudinal study. Results in the 2D-MR task were less clear-cut, with improved performance by the second session followed by a regression at later sessions in terms of speed-accuracy trade-off alone, but faster reaction times by both the second- and third-year sessions compared to the initial testing session. However, as suggested by Watkins et al. (2018), it is the rotation around the vertical axis, as assessed by the 3D block rotation task, which should most closely resemble the plane in which sign language input must be rotated during language processing. The 2D-MR task used here involved simple circular rotation, which does not map as clearly onto any visuospatial transformations during BSL use. In this sense, it is unsurprising that greater improvements over time were seen in the 3D-MR task and not the 2D-MR task, in tandem with L2 BSL learning during the degree program. The stronger improvement in the 3D-MR task involving rotation around the vertical axis, which is required during sign comprehension to understand someone signing from a different viewing angle; for example, provides some evidence that it is experienced with rotation in this plane through BSL practice, which is driving the improvement in 3D-MR, and not other types of rotation (e.g., signs that move from a palm-up to palm-down orientation). This also suggests that explicitly targeting improvement in comprehending sign language input from various angles would be beneficial.

For English reading comprehension, we did not see the same improvement over time as in Stone (2017), where Kirklees scores were significantly better by the end of the third year versus the start of the first year. Due to time constraints during testing, we could not repeat this task at our final third-year testing session. We assessed it for the final time at the end of the second year, which may be why we could not replicate this result. However, the Kirklees scores of our SLI students at the end of the second year were just below the level of Stone's third-year students, who, in turn, scored significantly lower than the working BSL-English interpreters who were also tested. Given the lack of improvement in this preliminary study and the conclusion of Stone (2017), it may be that experience working as an interpreter improves English skills (perhaps due to exposure to a wider range of vocabulary during interpreting), above and beyond any improvement seen during a university degree program. Age is generally a reliable predictor of vocabulary size (e.g., Ben-David et al., 2015), with better vocabulary scores as age increases. While it was not a significant covariate in this study, our sample of university students unsurprisingly did not have an even spread of our ages (two-thirds of our participants were aged 23 or under when the course began).

## Predictors of British Sign Language and sign language interpreting performance

There were several strong correlations between the cognitive/linguistic skills assessed and measures of BSL and SLI performance, some of which were statistically significant.

Starting with BSL outcomes, first-year BSL grades were significantly predicted by English reading comprehension, a correlation that was particularly strong for those with lower English and lower BSL scores (**Figure 3A**). This suggests that weaker English skills at the start of an SLI program may initially be a hindrance to L2 language learning in a new modality. However, SLI students who perform poorly in English initially seem to catch up by later testing sessions, by which point English comprehension was no longer predictive of BSL performance, which might be a consequence of exposure to English use in a university setting. Second-year BSL grades were correlated positively with 3D-MR skills in the same year, which fits with studies showing that MR improves gradually in line with sign language learning and does not just improve once sign language fluency is reached (Kubicek and Quandt, 2021). Interestingly, however, there was also a promisingly strong correlation, albeit not significant, between initial 3D-MR and third-year BSL-SRT scores (**Figure 5A**). This suggests that at least some of the success in BSL performance may be predictable from rotation scores at the outset of the degree, with an advantage for those who already start the SLI program with better MR skills (see, e.g., Kartheiser et al., 2022, who conclude that adult L2 signers can apply pre-existing non-linguistic spatial skills to the sign language they are learning). Regardless of initial MR skills, however, the findings suggest that students who do not improve at MR as they advance in the program do not perform as well as those who did. This may be true not only for BSL comprehension but for production as well. Second-year visuospatial WM was also a significant predictor of SRT scores at the final testing point (**Figure 4A**). Both MR and visuospatial WM are likely implicated in this task, where increasingly complex grammatical constructions in BSL must be reproduced. Furthermore, the BSL-SRT, like the copy-sign task and nonsense sign repetition tasks which were predictive of sign language performance in previous studies (López Gómez et al., 2007; Stone, 2017), involves phonological encoding and perceptuo-motor skills (see also Martinez and Singleton, 2018, who found that visuospatial short-term memory was predictive of sign learning, concluding that perceptuo-motor processes play a big role in individual sign learning). However, we did not replicate the result seen by Stone (2017), whereby initial performance on the phonological encoding task (MLAT Number Learning) was predictive of early BSL module grades.

In terms of SLI performance, we found that initial auditory WM was a promising indicator of second-year SLI grades (**Figure 7B**), suggesting it may be a useful assessment to conduct at student intake. While a digit span task was also used by Stone (2017) as a control measure of general cognitive ability, we employ it here as a measure of WM. Using an auditory version of the task has allowed us to explore the effects of different modalities in WM that previous SLI aptitude studies have not. There was also a significant correlation between SLI grades and 3D-MR in the third year ($r^2 = 0.54$, $t = 2.85$, $p = 0.029$). The third-year BSL-to-English interpreting task was also significantly correlated with second-year 2D-MR (**Figure 8A**), and the correlation with pre-degree 3D-MR was also very high ($r^2 = 0.48$, $t = 2.004$, $p = 0.101$; **Figure 8D**). The relationships here between MR skill and SLI outcomes were beyond what we had predicted: we had hypothesized that rotation would only be implicated directly in BSL tasks. However, it is plausible that rotation skills required during sign language comprehension and production (e.g., for syntactic and topographic uses of signing space) also come into play during measures of SLI itself. Furthermore, interpreting interactions also involve competent navigation of the spatial relations between interlocutors in physical space, where the viewing angle may be a factor. For example, in group scenarios, MR may be invoked to comprehend signing viewed from a non-frontal angle (Watkins et al., 2018). Lastly, performance on the SLI task from English to BSL was significantly correlated with second-year visuospatial WM. It may be that WM in different modalities is implicated in different ways during SLI when working in different directions: for example, visuospatial WM could be particularly important while planning and executing sign language production, as required by this task. Visuospatial WM may be required constantly for production in the visuospatial modality during spoken to signed interpreting, whereas when interpreting in the opposite direction, visuospatial WM is only engaged to attend to the spatial relations in signing space and is not required for the processing of specific signs.

Overall, the predictor assessments with the best and most consistent relationships to BSL and SLI performance were the MR tasks, in particular the 3D-MR task, and visuospatial WM. MR tasks were significant or marginally insignificant predictors of all the BSL/SLI outcome measures in this study: BSL grades, BSL sentence reproduction, SLI grades, and interpreting tasks in both directions, suggesting that MR is an essential skill for SLI educators to pay explicit attention to. Second-year visuospatial WM was a significant predictor of final BSL sentence repetition and strongly correlated with English-to-BSL interpreting performance, which we interpret as WM in the visuospatial modality being necessary for the BSL chunking, planning, and production required during both tasks. Most of the relationships between the cognitive/linguistic assessments and BSL/SLI performance emerged during re-testing at later sessions, although some notable exceptions may point toward skills that have predictive value at the outset of an SLI degree program. Initial 3D-MR skill was strongly correlated with the same two final-year outcomes as second-year visuospatial WM (SRT and English-to-BSL interpreting), highlighting the key role of cognition in the visuospatial modality for tasks involving planning and executing sign language production. We also saw that initial English vocabulary was important early on in L2 BSL learning, as well as a promising relationship between initial auditory WM and second-year SLI grades, suggesting both of these tasks are worth assessing at intake. Although our data are only exploratory, we have some initial evidence that supports Marks (2014) assertion that "[a] case can be made that there are cognitive skills that need to be present upon entry into [SLI] programs and others that can and need to be taught".

## Implications and future directions

This exploratory study highlights multiple domains worth further attention for SLI educators and researchers. To our knowledge, this is the first longitudinal study of SLI students to take baseline cognitive and linguistic measures before the start of the training program and relate them to performance on sign language and SLI tasks. We saw evidence that MR skill is implicated in not just sign language outcome measures but also in SLI performance, as well as links between visuospatial working memory and sign language production, in particular. We see some evidence that good English skills are initially important for early BSL learning, plus a possible role of initial auditory WM in SLI, which should be investigated by future studies.

Since this is still a preliminary study, however, we do not advocate excluding SLI program applicants at intake based on performance in any of the assessments conducted here. As Robinson (2022) highlights, there are issues with (mostly hearing) SLI educators further restricting the pool of potential SLI students at intake, particularly when interpreter demand already exceeds supply. Nevertheless, initial SLI aptitude testing could help to instead highlight other related careers that do not involve SLI, which may be more appropriate for some candidates, before struggling with a lengthy degree program with its associated expense. Future studies testing (visuospatial) cognitive skills at SLI course intake should also consider the additional stresses of assessments at interviews and issues, such as stereotype threat, i.e., where performance is affected by the awareness of a negative stereotype about one's social group. For example, women are often perceived to have poorer visuospatial skills, yet Moè and Pazzaglia (2006) found that the gender effect in MR could be negated by explicitly contradicting such stereotypes in task instructions. Such perceptions and stereotypes around visuospatial skills should be a consideration for aptitude testing, given that most (BSL) interpreters are women (Napier et al., 2021), as were most of the SLI students/applicants in this study. Regardless of initial baseline performance, our preliminary results should make SLI training programs aware of skills that would be worth tracking in their students, as well as the possibility to offer the additional targeted practice of skills, that are likely to improve throughout SLI training. Since it is now well-established that MR skill improves in tandem with sign language learning, it is also plausible that we could speed up this process by explicitly including rotation practice on assignments, tasks, or games, whether in a sign language context or not. This could be implicit practice with comprehension of sign language from different viewing angles in group or dialogue situations, where MR is likely implicated (see e.g., Watkins and Thompson, 2019). Alternatively, this could take the form of explicit training using gamified versions of MR tasks, like the ones used here, to try to boost performance, which should, in turn, feedback into signing and interpreting performance (see e.g., Passig and Eden, 2001). Furthermore, SLI educators can use these results to diversify the teaching and learning experience to better support students' development in these areas.

The title of Stone (2017), "the trials and tribulations of a longitudinal study," bears repeating, because aptitude studies of SLI students are complex endeavors. No single longitudinal study can address all the design, methodology, and data analysis issues. As Stone pointed out, we must be careful when interpreting the results of SLI aptitude studies, because most of the effect sizes are modest due to both the high levels of attrition and the small initial sample sizes. Even without the impacts of the pandemic and the high drop-out rate in SLI degree programs, studies on the SLI student population in the UK are always likely to be small in scale, due to the population to sample from not being very large (around 60 new degree students per year in total). Despite the small *n* in this exploratory study, we hope that our sample is somewhat representative, having tested most of the students across 2 year-groups from two of the three UK universities where SLI programs are taught in degree form. However, issues of sample size and statistical power will likely continue unless an international, multi-center study is organized. In this study, we had hoped to perform the first institution-level comparison in the UK, but participant recruitment and retention proved particularly difficult. Future large-scale longitudinal studies could also be facilitated by using online testing for many of the assessments, which we discovered worked well for students who had the means to take part remotely at later sessions. The tasks hosted on Pavlovia and GoReact were particularly successful. Online aptitude testing could facilitate access to a larger population of SLI students, however, factors, such as equity of access to technology and space to participate online, should be considered carefully. Given the extra adaptations to SLI and sign language teaching programs that were required due to the pandemic (see e.g., Hornstra, 2021; Katz, 2021), and the increasing use of online teaching methods in L2 sign language learning, even pre-pandemic (Ackerman et al., 2018), we hope this preliminary study demonstrates that online SLI aptitude testing is also feasible.

Further improvements to a future larger study could be gained by testing control groups of students on sign language-only degrees without the SLI components, and/or students on other degree programs; for example, a spoken language interpreting course with a comparable 'placement' year abroad. This would allow us to tease apart the respective effects of learning BSL vs. learning BSL *and* SLI within a degree program context, as well as any potential effects of simply completing a university degree or interpreting degree. Furthermore, more explicit attempts could be made to retain the participation of students who decide to withdraw from SLI programs. While we did not attempt to re-test students who had left their SLI course at later time points, continuing to include them as participants in the study would allow researchers to make stronger inferences about aptitude and the factors that can be attributed to changes in cognitive and linguistic skills over time. Since Stone (2017) also discovered several differences in skills between his student cohort and his group of experienced interpreters, another important avenue for future research would be to follow SLI program graduates as they transition to the workplace, to pinpoint how long it takes graduates to perform at the level of experienced interpreters. This could help highlight gaps in SLI training curricula.

## Conclusion

Overall, our exploratory study has revealed various new insights about cognitive and linguistic aptitude for L2 sign acquisition and SLI. Crucially, we have tested a range of assessments before the beginning of an SLI training program and followed both their development over time and their impact on signing and interpreting outcomes. Several of our preliminary results are consistent with previous findings suggesting the importance of both phonological encoding and visuospatial WM in SLI student success. We also tested new domains, such as MR, which, to our knowledge, has not been tracked in SLI students before. In particular, 3D-MR showed the biggest improvement over time and was strongly correlated with a range of BSL and SLI outcome measures, as well as there being some indication that pre-degree skill in this domain may be associated with later signing and interpreting performance. We also argue that visuospatial WM and 3D-MR are particularly important for tasks involving sign language production, with implications of modality for broader theories of cognition and language aptitude. These preliminary results will hopefully inform SLI educators about relevant skills to identify and support during training programs, as well as provide a basis for longer-term studies of SLI aptitude through to professional proficiency.

## Data availability statement

The datasets presented in this study can be found in the Open Science Framework (OSF) repository for this manuscript: https://osf.io/kjctg.

## Ethics statement

This study was reviewed and approved by University of Birmingham Science, Technology, Engineering and Mathematics Ethical Review Committee (ERN_18-1170). The participants provided their written informed consent to participate in this study.

## Author contributions

All authors developed the idea for this study. FW wrote the first draft of the manuscript and collected and analyzed the majority of the data, with data collection assistance from RT and SW. SW and CS facilitated initial data collection sessions and created and coded the final interpreting tasks. RT also coded some data and assisted with the analysis. All authors were responsible for revising the article.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Publisher's note



## References

Ackerman, J. M., Wolsey, J.-L. A., and Clark, M. D. (2018). Locations of L2/Ln sign language pedagogy. *Creat. Educ.* 9:2037. doi: 10.4236/ce.2018.913148

Anssari-Naim, S. (2021). A comparative assessment of listening span and self-efficacy in simultaneous interpreting training. *Sendebar* 32, 167–176. doi: 10.30827/sendebar.v32.16868

Babcock, L., Capizzi, M., Arbula, S., and Vallesi, A. (2017). Short-term memory improvement after simultaneous interpretation training. *J. Cogn. Enhanc.* 1, 254–267. doi: 10.1007/s41465-017-0011-x

Baddeley, A. (2012). Working memory: theories, models, and controversies. *Annu. Rev. Psychol.* 63, 1–29. doi: 10.1146/annurev-psych-120710-100422

Baddeley, A. D., Hitch, G. J., and Allen, R. J. (2009). Working memory and binding in sentence recall. *J. Memory Lang.* 61, 438–456. doi: 10.1016/j.jml.2009.05.004

Bates, D., Maechler, M., Bolker, B., and Walker, S. (2015). Fitting linear mixed-effects models using lme4. *J. Statistical Software* 67, 1–48. doi: 10.18637/jss.v067.i01

Beal, J. S., Scheetz, N., Trussell, J., McAllister, A., and Listman, J. (2018). University American Sign Language learners: longitudinal self- and faculty evaluation ratings. *J. Interpretation* 26:5.

Ben-David, B. M., Hadas, E., Goy, H., and Schneider, B. A. (2015). "Older is always better": age-related differences in vocabulary scores across 16 years. *Psychol. Aging* 30, 856–862. doi: 10.1037/pag0000051

Berteau-Pavy, D., Raber, J., and Piper, B. J. (2011). *Contribution of age, but not sex, to mental rotation performance in a community sample (PEBL technical report 2011–2012)*. Available online at: http://sites.google.com/site/pebltechnicalreports/home/pebl-technical-report-2011-02 (accessed April 10, 2019).

Bontempo, K., and Napier, J. (2009). "Getting it right from the start: program admission testing of signed language interpreters," in *Testing and Assessment in Translation and Interpreting Studies*, eds C. V. Angelelli and H. E. Jacobson (Amsterdam: John Benjamins Publishing Company), 247–295. doi: 10.1075/ata.xiv.13bon

Bontempo, K., Napier, J., Hayes, L., and Brashear, V. (2014). Does personality matter? an international study of sign language interpreter disposition. *Trans. Interpreting* 6, 23–46. doi: 10.12807/ti.106201.2014.a02

Carroll, J., and Sapon, S. (1959). *Modern language aptitude test*. New York, NY: The Psychological Corporation.

Carroll, J., Sapon, S., Reed, D., and Stansfield, C. (2010). *Manual for the MLAT*. Bethesda, MD: Second Language Testing Inc.

Carver, C. S., and White, T. L. (1994). Behavioral inhibition, behavioral activation, and affective responses to impending reward and punishment: the BIS/BAS Scales. *J. Pers. Soc. Psychol.* 67, 319–333. doi: 10.1037/0022-3514.67.2.319

CFA (2012). *Interpreting: National Occupational Standards*. Charlottesville, VA: CFA.

Chmiel, A. (2018). In search of the working memory advantage in conference interpreting - training, experience and task effects. *Int. J. Bilingualism* 22, 371–384. doi: 10.1177/1367006916681082

Christoffels, I. K., de Groot, A. M. B., and Kroll, J. F. (2006). Memory and language skills in simultaneous interpreters: the role of expertise and language proficiency. *J. Memory Lang.* 54, 324–345. doi: 10.1016/j.jml.2005.12.004

Cokely, D. (1986). College level sign language programs: a resource list. *Sign Lang. Stud.* 50, 78–92. doi: 10.1353/sls.1986.0026

Cormier, K., Adam, R., Rowley, K., Woll, B., and Atkinson, J. (2012). The BSL sentence reproduction test: exploring age-of-acquisition effects in British deaf adults. *Paper presented at the 34th annual meeting of the german association of linguistics*, Frankfurt am Main.

Corsi, P. M. (1972). *Human Memory and the Medial Temporal Region of the Brain*. Doctoral thesis, Montreal, MTL: McGill University.

Croschere, J., Dupey, L., Hilliard, M., Koehn, H., and Mayra, K. (2012). *PEBL technical report series: PEBL technical report series [on-line], #2012-03.* Available online at: https://sites.google.com/site/pebltechnicalreports/home/2012/pebl-technical-report-2012-03

Department for Work and Pensions [DWP] (2017). *Market Review of British Sign Language and Communications Provision for People who are Deaf or have Hearing Loss*. London: DWP.

Dong, Y., Liu, Y., and Cai, R. (2018). How does consecutive interpreting training influence working memory: a longitudinal study of potential links between the two. *Front. Psychol.* 9:875. doi: 10.3389/fpsyg.2018.00875

Ebi, K. (2019). *How Climate Change could make Our Food Less Nutritious*. Vancouver, BC: TED.

Emmorey, K. (1998). The impact of sign language use on visuospatial cognition. *Psychol. Perspect. Deafness* 2, 19–52.

Emmorey, K. (2002). *Language, Cognition, and the Brain: Insights From Sign Language Research*. London: Psychology Press. doi: 10.4324/9781410603982

Emmorey, K., Klima, E., and Hickok, G. (1998). Mental rotation within linguistic and non-linguistic domains in users of American Sign Language. *Cognition* 68, 221–246. doi: 10.1016/S0010-0277(98)00054-7

Forbes, S. (2020). *PupillometryR: A Unified Pipeline for Pupillometry Data. R Package Version 0.0.3*. Available online at: https://CRAN.R-project.org/package=PupillometryR.

Frishberg, N. (1986). *Interpreting: An Introduction*. Silver Spring, MD: RID Publications.

Ganis, G., and Kievit, R. (2015). A new set of three-dimensional shapes for investigating mental rotation processes: validation data and stimulus set. *J. Open Psychol. Data* 3:e3. doi: 10.5334/jopd.ai

Gile, D. (1997). Conference interpreting as a cognitive management problem. *Appl. Psychol.* 3, 196–214.

GoReact (2022). *Video + Feedback for Sign & Foreign Languages*. Orem: Video Assessment For Skill Development & Feedback, GoReact.

Grbić, N. (2009). "Sign language interpreter training in Austria: an integrated approach," in *International Perspectives on Sign Language Interpreter Education*, ed. J. Napier (Washington, D.C: Gallaudet University Press), 3–14.

Hall, M. L., and Bavelier, D. (2011). Short-term memory stages in sign vs. speech: the source of the serial span discrepancy. *Cognition* 120, 54–66. doi: 10.1016/j.cognition.2011.02.014

Haug, T., Nussbaumer, D., and Stocker, H. (2019a). *Gebärdensprachdolmetschen: Die Bedeutung der Kognition beim Dolmetschen*. Zürich: Forschungskolloquium.

Haug, T., Nussbaumer, D., and Stocker, H. (2019b). Die Entwicklung von Instrumenten zur Überprüfung von kognitiven Fähigkeiten, gebärdensprachlicher Kompetenz und Dolmetschleistung von Gebärdensprachdolmetscherinnen. *Das Zeichen* 111, 130–143.

Hebbali, A. (2020). *blorr: Tools for Developing Binary Logistic Regression Models. R package version 0.3.0*. Available online at: https://CRAN.R-project.org/package=blorr.

Hedderly, R. (1996). Vernon-Warden reading test (Revised). *Dyslexia Rev.* 7, 11–16.

Hornstra, K. (2021). *Teaching Through a Screen: The Challenges of Virtual American Sign Language*. Harrisonburg, VA: The News Record.

Huhtinen, K. (2014). *Admittance Tests 2002-2008 of the Degree Programme in Sign Language Interpretation at the Diaconia University of Applied Sciences: Student Selection, Admittance Test Results and their Connections to Study Success.* MA thesis, Finland: Diaconia University of Applied Sciences.

Humphrey, J. (1994). "Effective screening procedures for entering students in interpreter education," in *Proceedings of the tenth national convention of the conference of interpreter trainers: Mapping our course: A collaborative venture*, ed. E. A. Winston (Charlotte, NC: Interpreter Trainer). doi: 10.1097/JSM.0b013e3181d44705

Hunt, D. I. J., and Nicodemus, B. (2014). "Gatekeeping in ASL-English interpreter education programs: assessing the suitability of students for professional practice," in *Proceedings of the Biennial Conference - Our Roots: The Essence of Our Future Conference Proceedings*, eds D. I. J. Hunt and S. Hafer (Portland, ORE), 44–60.

Jaeggi, S. M., Buschkuehl, M., Jonides, J., and Perrig, W. J. (2008). Improving fluid intelligence with training on working memory. *Proc. Natl. Acad. Sci. U S A.* 105, 6829–6833. doi: 10.1073/pnas.0801268105

Jones, M. L., and Quigley, S. P. (1974). Selection, evaluation and classification of interpreters. *J. Am. Deafness Rehabil. Assoc.* 8, 79–83.

Kartheiser, G., Kurz, K. B., Emmorey, K., Brozdowski, C., and Hauser, P. C. (2022). Nonlinguistic spatial cognitive skills facilitate second language learning in the visual modality. *Paper presented at the 4th international conference on sign language acquisition*. (Boston, MA: Boston University Wheelock College of Education & Human Development).

Katz, S. (2021). *The COVID Zoom Boom is Reshaping Sign Language*. Berlin: Scientific American.

Kaufman, A. S., and Kaufman, N. L. (2004). *Kaufman Brief Intelligence Test*, 2nd Edn. London: Pearson, Inc.

Kazak, A. E. (2018). Editorial: journal article reporting standards. *Am. Psychol.* 73, 1–2. doi: 10.1037/amp0000263

Keehner, M., and Gathercole, S. E. (2007). Cognitive adaptations arising from nonnative experience of sign language in hearing adults. *Memory Cogn.* 35, 752–761. doi: 10.3758/BF03193312

Kessels, R. P. C., van Zandvoort, M. J. E., Postma, A., Kappelle, L. J., and de Haan, E. H. F. (2000). The corsi block-tapping task: standardization and normative data. *Appl. Neuropsychol.* 7, 252–258. doi: 10.1207/S15324826AN0704_8

Kubicek, E., and Quandt, L. C. (2021). A positive relationship between sign language comprehension and mental rotation abilities. *J. Deaf Stud. Deaf Educ.* 26, 1–12. doi: 10.1093/deafed/enaa030

Lara Burgos, P., and de los Santos Rodríguez, E. (2000). *Técnicas de Interpretación de Lengua de Signos*. Madrid: CNSE.

Leitner, K. (2012). *Studienabbrüche im Studiengang ÖGS - Ursachen und Konsequenzen*. Graz: Karl-Franzens-Universität. MA Thesis.

Lemon, J. (2006). Plotrix: a package in the red light district of R. *R-News* 6, 8–12.

Liesefeld, H. R., Fu, X., and Zimmer, H. D. (2015). Fast and careless or careful and slow? apparent holistic processing in mental rotation is explained by speed-accuracy trade-offs. *J. Exp. Psychol. Learn. Memory Cogn.* 41, 1140–1151. doi: 10.1037/xlm0000081

Liesefeld, H. R., and Janczyk, M. (2019). Combining speed and accuracy to control for speed-accuracy trade-offs(?). *Behav. Res. Methods* 51, 40–60. doi: 10.3758/s13428-018-1076-x

Lin, Y., Lv, Q., and Liang, J. (2018). Predicting fluency with language proficiency, working memory, and directionality in simultaneous interpreting. *Front. Psychol.* 9:1543. doi: 10.3389/fpsyg.2018.01543

Liu, M., Schallert, D. L., and Carroll, P. J. (2004). Working memory and expertise in simultaneous interpreting. *Interpreting* 6, 19–42. doi: 10.1075/intp.6.1.04liu

López Gómez, M. J., Molina, T. B., Benítez, P. P., Santiago, and de Torres, J. (2007). Predicting proficiency in signed language interpreting: a preliminary study. *Interpreting* 9, 71–93. doi: 10.1075/intp.9.1.05lop

Lüdecke, D. (2021). *sjPlot: Data Visualization for Statistics in Social Science. R Package Version 2.8.10*. Available online at: https://CRAN.R-project.org/package=sjPlot.

Macnamara, B. (2009). Interpreter cognitive aptitudes. *J. Interpretation* 2008-2009, 9–32.

Macnamara, B. N., and Conway, A. R. A. (2016). Working memory capacity as a predictor of simultaneous language interpreting performance. *J. Appl. Res. Memory Cogn.* 5, 434–444. doi: 10.1016/j.jarmac.2015.12.001

Macnamara, B. N., Moore, A. B., Kegl, J. A., and Conway, A. R. A. (2011). Domain-general cognitive abilities and simultaneous interpreting skill. *Interpreting* 13, 121–142. doi: 10.1075/intp.13.1.08mac

Madley-Dowd, P., Hughes, R., Tilling, K., and Heron, J. (2019). The proportion of missing data should not be used to guide decisions on multiple imputation. *J. Clin. Epidemiol.* 110, 63–73. doi: 10.1016/j.jclinepi.2019.02.016

Marks, J. (2014). "Cognitive measures in interpreter education: an examination of admissions screening in ASL-English interpreter education programs," in *Proceedings of the Our Roots: The Essence of Our Future Conference Proceedings*, eds D. I. J. Hunt and S. Hafer (St, Greeley, CO).

Martinez, D., and Singleton, J. L. (2018). Predicting sign learning in hearing adults: the role of perceptual-motor (and phonological?) processes. *Appl. Psycholinguistics* 39, 905–931. doi: 10.1017/S0142716418000048

Martinez, D., and Singleton, J. L. (2019). Individual differences in lexical learning across two language modalities: sign learning, word learning, and their relationship in hearing non-signing adults. *Acta Psychol.* 198:102892. doi: 10.1016/j.actpsy.2019.102892

Mayberry, R. I., and Fischer, S. D. (1989). Looking through phonological shape to lexical meaning: the bottleneck of non-native sign language processing. *Memory Cogn.* 17, 740–754. doi: 10.3758/BF03202635

McKee, D. (1987). *An Analysis of Specialized Cognitive Functions in Deaf and Hearing Signers*. Unpublished doctoral dissertation, Pittsburgh, PA: University of Pittsburgh.

Moè, A., and Pazzaglia, F. (2006). Following the instructions!: effects of gender beliefs in mental rotation. *Learn. Individual Differ.* 16, 369–377. doi: 10.1016/j.lindif.2007.01.002

Monikowski, C., and Peterson, R. (2005). "Service learning in interpreting education: living and learning," in *Sign Language Interpreting and Interpreter Education: Direction for Research and Practice*, eds M. Marschark, R. Peterson, and E. A. Winston (Oxford: Oxford University Press), 188–207. doi: 10.1093/acprof/9780195176940.003.0008

Morales, J., Padilla, F., Gómez-Ariza, C. J., and Bajo, M. T. (2015). Simultaneous interpretation selectively influences working memory and attentional networks. *Acta Psychol.* 155, 82–91. doi: 10.1016/j.actpsy.2014.12.004

Moser-Mercer, B. (1985). Screening potential interpreters. *Meta* 30:97. doi: 10.7202/003631ar

Mueller, S. T. (2014). *PEBL: The Psychology Experiment Building Language (Version 0.14)*. Available online at: http://pebl.sourceforge.net

Mueller, S. T., and Piper, B. J. (2014). The psychology experiment building language (PEBL) and PEBL test battery. *J. Neurosci. Methods* 222, 250–259.

Müller, K. (2020). *here: A Simpler Way to Find Your Files. R package version 1.0.1*. Available online at: https://CRAN.R-project.org/package=here.

Nakano, S. (2021). A review of studies related to the aptitude in sign language acquisition by hearing adults: cognitive factors. *Bull. Faculty Co-Educ.* 70, 165–174.

Napier, J., Skinner, R., Adam, R., Stone, C., Pratt, S., and Obasi, C. (2021). *A Demographic Snapshot of the Profession: The 2021 Census of Sign Language Translators & Interpreters in the UK*. London: Association of Sign Language Interpreters UK & Heriot-Watt University.

Nicodemus, B., and Emmorey, K. (2013). Direction asymmetries in spoken and signed language interpreting. *Bilingualism: Lang. Cogn.* 16, 624–636. doi: 10.1017/S1366728912000521

Ortega, G., and Morgan, G. (2015). Input processing at first exposure to a sign language. *Second Lang. Res.* 31, 443–463. doi: 10.1177/0267658315576822

Padden, C. A. (2000). Simultaneous interpreting across modalities. *Interpreting* 5, 169–185. doi: 10.1075/intp.5.2.07pad

Padilla, F., Bajo, M. T., and Macizo, P. (2005). Articulatory suppression in language interpretation: working memory capacity, dual tasking and word knowledge. *Bilingualism: Lang. Cogn.* 8, 207–219. doi: 10.1017/S1366728905002269

Passig, D., and Eden, S. (2001). Virtual reality as a tool for improving spatial rotation among deaf and hard-of-hearing children. *CyberPsychol. Behav.* 4, 681–686. doi: 10.1089/109493101753376623

Patton, J. H., Stanford, M. S., and Barratt, E. S. (1995). Factor structure of the barratt impulsiveness scale. *J. Clin. Psychol.* 51, 768–774. doi: 10.1002/1097-4679(199511)51:6<768::AID-JCLP2270510607>3.0.CO;2-1

Pedersen, T. L. (2020). *patchwork: The Composer of Plots. R Package Version 1.1.1*. Available online at: https://CRAN.R-project.org/package=patchwork.

Peirce, J., Hirst, R., and MacAskill, M. (2022). *Building Experiments in PsychoPy*, 2nd Edn. Thousand Oaks, CA: SAGE Publishing.

Peterson, R. (1999). "The perceptions of deafness and language learning of incoming ASL students," in *Proceedings of the 16th National Convention of the Registry of Interpreters for the Deaf*. (Morrisville).

Pimsleur, P. (1966). *The Pimsleur Language Aptitude Battery*. New York, NY: Harcourt, Brace & Jovanovic.

Pivac, L. (2014). "Learner autonomy in New Zealand Sign Language interpreting students," in *Teaching and Learning Signed Languages: International Perspectives and Practices*, eds D. McKee, R. S. Rosen, and R. L. McKee (London: Palgrave Macmillan). doi: 10.1057/9781137312495_10

R Core Team (2021). *R: A Language and Environment for Statistical Computing*. Vienna: R Foundation for Statistical Computing.

Robinson, O. (2022). *Abled arrogance, not linguistic carework. Medium*. Available online at: https://notanangrydeafperson.medium.com/abled-arrogance-not-linguistic-carework-77434eae2cee

Robinson, O., and Henner, J. (2018). Authentic voices, authentic encounters: Cripping the university through American Sign Language. *Disabil. Stud. Q.* 38, 1–20. doi: 10.18061/dsq.v38i4.6111

Russo, M. (2011). Aptitude testing over the years. *Interpreting* 13, 5–30. doi: 10.1075/intp.13.1.02rus

Russo, M. (2014). Testing aptitude for interpreting: the predictive value of oral paraphrasing, with synonyms and coherence as assessment parameters. *Interpreting* 16, 1–18. doi: 10.1075/intp.16.1.01rus

Russo, M., and Pippa, S. (2004). Aptitude to interpreting: preliminary results of a testing methodology based on paraphrase. *Meta* 49, 409–432. doi: 10.7202/009367ar

Seal, B. C. (2004). Psychological testing of sign language interpreters. *J. Deaf Stud. Deaf Educ.* 9, 39–52. doi: 10.1093/deafed/enh010

Shaw, S. (2011). Cognitive and motivational contributors to aptitude: a study of spoken and signed language interpreting students. *Interpreting* 13, 70–84. doi: 10.1075/intp.13.1.05sha

Shaw, S., and Hughes, G. (2006). Essential characteristics of sign language interpreting students: Perspectives of students and faculty. *Interpreting* 8, 195–221. doi: 10.1075/intp.8.2.05sha

Shepard, S., and Metzler, D. (1988). Mental rotation: effects of dimensionality of objects and type of task. *J. Exp. Psychol. Hum. Percept. Perform.* 14, 3–11. doi: 10.1037/0096-1523.14.1.3

Speekenbrink, M. (2021). *sdamr: Statistics: Data Analysis and Modelling. R Package Version 0.1.0*. Available online at: https://CRAN.R-project.org/package=sdamr.

Stauffer, L. K., and Shaw, S. (2006). Personality characteristics for success in interpreting courses: Perceptions of spoken and sign language interpretation students. *J. Interpret.* 6, 11–25.

Stone, C. (2017). Sign language interpreter aptitude: the trials and tribulations of a longitudinal study. *Trans. Interpreting* 9:16. doi: 10.12807/ti.109201.2017.a06

Strobach, T., Becker, M., Schubert, T., and Kühn, S. (2015). Better dual-task processing in simultaneous interpreters. *Front. Psychol.* 6:1590. doi: 10.3389/fpsyg.2015.01590

Talbot, K. F., and Haude, R. H. (1993). The relation between sign language skill and spatial visualization ability: mental rotation of three-dimensional objects. *Percept. Mot. Skills* 77, 1387–1391. doi: 10.2466/pms.1993.77.3f.1387

Timarová, Š, and Ungoed-Thomas, H. (2008). Admission testing for interpreting courses. *Interpreter Translator Trainer* 2, 29–46. doi: 10.1080/1750399X.2008.10798765

Torchiano, M. (2020). *effsize: Efficient Effect Size Computation. R Package Version 0.8.1*.

Tzou, Y.-Z., Eslami, Z. R., Chen, H.-C., and Vaid, J. (2012). Effect of language proficiency and degree of formal training in simultaneous interpreting on working memory and interpreting performance: evidence from Mandarin-English speakers. *Int. J. Bilingualism* 16, 213–227. doi: 10.1177/1367006911403197

van Dijk, R., Christoffels, I., Postma, A., and Hermans, D. (2012). The relation between the working memory skills of sign language interpreters and the quality of their interpretations. *Bilingualism* 15, 340–350. doi: 10.1017/S1366728911000198

Volk, C. (2014). *Sign Language Interpreter Education: Time for a National Call to Action*. Marietta: StreetLeverage.

Wang, J. (2016). The relationship between working memory capacity and simultaneous interpreting performance: a mixed methods study on professional Auslan/English interpreters. *Interpreting* 18, 1–33. doi: 10.1075/intp.18.1.01wan

Wang, J., and Napier, J. (2013). Signed language working memory capacity of signed language interpreters and deaf signers. *J. Deaf Studies Deaf Educ.* 18, 271–286. doi: 10.1093/deafed/ens068

Warden, V. B. (1956). *Construction and Standardisation of a Reading Test*. Unpublished MA thesis, London: University of London.

Watkins, F., Abdlkarim, D., and Thompson, R. L. (2018). L1 and L2 sign recognition: the role of visual angle. *Paper presented at the 3rd international conference on sign language acquisition*. (İstanbul: Koç Üniversitesi).

Watkins, F., and Thompson, R. L. (2019). Angle-diverse input and sign vocabulary learning in novice l2 british sign language learners. *Paper presented at the theoretical issues in sign language research 13*. (Hamburg: Universität Hamburg).

Webb, S. (2017). *Job Demands, Job Resources, Wellbeing and Student Outcomes: A Study of Sign Language Interpreter Educators' Perceptions*. PhD thesis, Edinburgh: Heriot-Watt University.

Wickham, H., Averick, M., Bryan, J., Chang, W., McGowan, L. D. A., François, R., et al. (2019). Welcome to the tidyverse. *J. Open Source Software* 4:1686. doi: 10.21105/joss.01686

Wickham, H., and Seidel, D. (2020). *Scales: Scale Functions for Visualization. R Package Version 1.1.1*. Available online at: https://CRAN.R-project.org/package=scales.

Williams, J., Darcy, I., and Newman, S. (2015). Second language working memory deficits and plasticity in hearing bimodal learners of sign language. *Psychol. Lang. Commun.* 19, 128–148. doi: 10.1515/plc-2015-0008

Williams, J., and Newman, S. (2016). Phonological substitution errors in L2 ASL sentence processing by hearing M2L2 learners. *Second Lang. Res.* 32, 347–366. doi: 10.1177/0267658315626211

Williams, J. T., Darcy, I., and Newman, S. D. (2017). The beneficial role of L1 spoken language skills on initial L2 sign language learning: cognitive and linguistic predictors of M2L2 acquisition. *Stud. Second Lang. Acquisition* 39, 833–850. doi: 10.1017/S0272263116000322

Wilson, M., and Emmorey, K. (2003). The effect of irrelevant visual input on working memory for sign language. *J. Deaf Stud. Deaf Educ.* 8, 97–103. doi: 10.1093/deafed/eng010

Witter-Merithew, A., and Johnson, L. (2005). *Toward competent practice: Conversations with stakeholders*. San Antonio, TX: Registry of Interpreters for the Deaf.

Yorke, M., Bridges, P., and Woolf, H. (2000). Mark distributions and marking practices in UK higher education: some challenging issues. *Act. Learn. Higher Educ.* 1, 7–27. doi: 10.1177/1469787400001001002

Yudes, C., Macizo, P., and Bajo, T. (2011). The influence of expertise in simultaneous interpreting on non-verbal executive processes. *Front. Psychol.* 2:309. doi: 10.3389/fpsyg.2011.00309

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# Are palm reversals the pronoun reversals of sign language? Evidence from a fingerspelling task

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Acquisition of pronominal forms by children with autism spectrum disorder (ASD) continues to garner significant attention due to the unusual ways that such children produce and comprehend them. In particular, pronoun reversal errors (e.g., using the 2nd-person pronoun "you" to refer to oneself) have been noted in the speech of children with ASD since the very first report of the disorder. In more recent years, investigations of the signing of deaf children with ASD have documented a different phenomenon: palm orientation reversals, such that signs typically produced with an outward-facing palm are produced with the palm towards the signer, or vice versa. At the same time, true pronoun reversals have yet to be documented in the signing of deaf children on the autism spectrum. These two curious facts have led us to ask if there is evidence that palm orientation reversals in signed languages and pronoun reversals in spoken languages could be surface manifestations of the same underlying differences present in ASD. In this paper we seek to establish whether there is evidence for such an analogy, by comparing the ages at which the two phenomena appear in both typically-developing (TD) children and those with ASD, the frequency and consistency with which they appear, and their relationships with other linguistic and cognitive skills. Data are presented from a fingerspelling task given to a sample of 17 native-signing children with ASD and 24 native-signing TD children. We conclude that there are provocative parallels between pronoun reversals in spoken languages and palm reversals in signed languages, though more research is needed to definitively answer these questions.

KEYWORDS
**autism spectrum disorder, ASL, pronouns, modality, fingerspelling**

## Introduction

Over the past decade we have pursued a new line of research investigating the linguistic development of children with autism spectrum disorder (ASD) exposed to a signed language from birth by their Deaf parents; these children are native signers. This work is of theoretical interest because such studies show how children with ASD acquire language in a modality other than speech. As such, they have the potential to shed new light on how language acquisition occurs in ASD, how acquisition is related to and dependent on particular social skills, and how language modality affects acquisition. So far, these studies have documented several phenomena that mirror the development of speaking children with ASD, such as pronoun avoidance (Jordan, 1989; Lee et al., 1994; Shield et al., 2015), difficulties with theory of mind (Shield et al., 2016), articulation challenges (Bhat et al., 2016; Shield et al., 2017), and atypical perception and production of facial expressions (Denmark et al., 2014, 2019). At the same time, one well-documented feature of the spoken language of children with ASD – pronoun reversals (Kanner, 1943; Naigles et al., 2016) – has yet to be clearly documented in signing children with ASD, despite attempts to elicit sign language pronouns (Shield et al., 2015). Complementing this striking absence is the documentation of a different kind of reversal – the reversal of the orientation of the palm in the signing of such children (Shield and Meier, 2012; Shield et al., 2020). Such reversals have also been documented in the imitation of gestures by hearing children with ASD (Ohta, 1987), and have been interpreted as being due to differences in imitation style (Shield and Meier, 2018), difficulties with "self-other mapping" (that is, the ability to faithfully reproduce the body movements of others, Rogers and Pennington, 1991), or with breakdowns in intersubjective identification (Hobson and Hobson, 2007).

Pronoun reversals in speech and palm orientation reversals in sign share a fundamental quality: they both reflect the wholesale or gestalt reproduction of a linguistic form produced by a speaker/signer, as it is perceived by the interlocutor. In the case of pronoun reversals, children typically produce the second-person pronoun (e.g., "you" in English) in reference to self, using the pronoun that others use to refer to the child. In the case of palm orientation reversals, children reproduce signs as they appear from their perspective, rather than reversing what they see in order to faithfully produce the sign. Faithful reproduction of a sign requires that the child produce that sign as it would be produced from the signer's perspective, not their own. It is important to note that we would not predict signed pronoun reversals to result from such a gestalt imitation style: if the child were to produce the ASL pronoun YOU as it appears from their own perspective, they would (paradoxically) produce an indexical point towards their own body, with or without contact with the torso, which would approximate the appropriate ASL pronoun ME.

Despite the fact that these reversals occur in one linguistic domain in speech (deictic pronouns) and in another domain in sign (articulation of the sign itself), it appears possible that both phenomena could be grounded in the same underlying difference – a tendency to reproduce linguistic forms in a gestalt fashion without undergoing a shift – from *you* to *I* for spoken pronouns and from the addressee's (i.e., the child's) perspective on palm orientation to the signer's perspective on palm orientation.

Given the conspicuous lack, thus far, of documented pronoun reversals in the signing of children with ASD, paired with the clear documentation of palm orientation reversals in the same children, in this paper we ask if there is any evidence that palm orientation reversals in sign could be analogous to pronoun reversals in speech. By analogous, we mean that they have the same underlying causes, despite having different surface forms.

What kind of evidence might be sufficient to prove or disprove such a hypothesis? One way to establish such a connection would be to show that pronoun reversals in speech and palm orientation reversals in sign occur:

(a) at similar chronological ages (for both typical and atypical children);
(b) at similar frequencies and with similar (in)consistency within the population of children with ASD;
(c) in children with similar linguistic and/or cognitive profiles, and/or
(d) in individual children with ASD who are bimodal bilinguals in a signed language and in a spoken language.

If we were to find similarities such as the above, then we might be able to start to build an argument that these could be analogous phenomena – in other words, that the acquisition of language by children with ASD is marked by a similar approach by the learner which, however, results in different surface forms in signed and spoken languages.

In the section that follows, we will briefly lay out what is known about pronoun reversals in speaking children, in order to establish a baseline against which to compare the production of palm orientation reversals by signing children as reported in prior studies and in the current study. We will focus primarily on points (b) and (c) above, with an admittedly incomplete picture regarding point (a), especially with regard to typical children. We do not have data that would address point (d), but suggest that this is a promising avenue for future research.

## Pronoun reversals in speaking children

### When do pronoun reversals occur?

#### Typical development

First-and second-person forms (*I, me, you*) typically emerge around the age of 1;6 or when children's MLU reaches 2.5 (Bloom et al., 1975). A number of studies have documented that typically-developing (TD) hearing children sometimes reverse first-and second-person pronouns early on in development, generally before the age of 2;6. Dale and Crain-Thoreson (1993) found that 17 of 30 precocious speakers reversed pronouns at age 1;8. Several case studies have also documented pronoun reversals in very young TD children, especially early talkers. Evans and Demuth (2012) found that one TD child reversed pronouns from age 1;7 to 2;4; Chiat (1982) reported a TD child who reversed both first-and second-person pronouns between ages 2;4–2;5; and Oshima-Takane (1992) discussed another TD child who produced reversed pronouns between 1;11 and 2;4.

In the acquisition of signed languages, there are indications that some very young TD signing children also go through a phase of pronoun reversal between the ages of 1;3–2;0 (Petitto, 1987; Jackson, 1989; Pizzuto, 1990), despite the phonological similarity of sign-language pronouns to gestural points, which typically emerge by 8–10 months (Bates and Dick, 2002). Such errors have been interpreted as the child's treatment of the indexical point as a frozen lexical form, such that a point away from the child's body toward an interlocutor (thereby producing a sign that looks like the sign YOU) is meant to refer to the child ("me"). Thus, in both hearing and deaf TD children, pronoun reversals most often occur before age 2;6, and appear to be the result of linguistic development that has outpaced the social or pragmatic abilities necessary to use such forms in an adult way.

### Atypical development

For children with ASD, reversals have also been found to start early, but often persist well past the age of 2;6. Evans and Demuth (2012) found that reversals started at 1;5 and continued through the end of data collection at age 2;11 in their single subject with ASD. Naigles et al. (2016) studied 15 children with ASD between the ages of 2;6 and 4;6, finding reversed pronouns in older children as well as younger children.

Several studies attest to continued pronoun reversal by children with ASD well into the school-age years and even adolescence. In the first modern report of ASD, Kanner (1943) observed that 7 of 11 children ranging in age from 3;6 to 6 years reversed or confused pronouns.[1] Tager-Flusberg (1994) found that six children with ASD between the ages of 3;4 and 9;9 produced 220 reversed pronouns (13.2% of the total pronouns in the corpus). Jordan (1989) found that three children with ASD reversed pronouns in a sample of 11 children and adolescents with ASD between the ages of 6;8 and 16;5, and an MLU between 1.1–4.8 ($M = 2.4$). Finally, Lee et al. (1994) found that three of 25 adolescents with ASD ages 14–17 made pronoun reversal errors, producing "I" instead of "you."

Thus, pronoun reversals are attested in children with ASD beyond the age at which they typically disappear (~2;6), into later childhood and even into adolescence.

1 Kanner's report included the following information about his subjects' uses of pronouns: Alfred L. "confuse[d] pronouns" (p. 233) at age three-and-a-half; Charles N.'s "vocabulary [wa]s good, except for pronouns" (p. 236) at age four-and-a-half; John F. "used the pronoun of the second person when referring to himself" (p. 238) until age four-and-a-half, when he "began gradually to use pronouns adequately" (p. 238); Elaine C. at age five "did not use pronouns correctly" (p. 240) and at age 7;2 "never use[d] the personal pronouns of the first and second persons correctly" (p. 241); Paul G. made pronoun errors at age five ("all statements pertaining to himself were made in the second person," p. 228); Donald T. reversed pronouns in echolalic contexts at ages 5;1–5;5, but no longer did at age 7;7; and Frederick W. "ha[d] great difficulty in learning the proper use of personal pronouns" (p. 223) at age six.

## How frequently or consistently do pronoun reversals occur?

### Typical development

Most studies of pronoun development in TD children report infrequent pronoun reversals (Loveland, 1984; Dale and Crain-Thoreson, 1993; Evans and Demuth, 2012; Naigles et al., 2016), both with respect to the percentage of children who produce the reversals, and the percentage of pronouns that are reversed by such children. For example, Loveland (1984, p. 548) reported pronoun reversals in a group of 11 TD children aged 2;0–2;3, but "no children in this study were observed to make frequent or consistent pronoun-production errors of the reversal type." More recently, Naigles et al. (2016) found that 1.67% of pronouns produced by TD children were reversed between 1;9–2;3, which decreased to under 1% of pronouns between 2;9–3;3. Evans and Demuth (2012) reported that their TD participant reversed 3% of 1st-person pronouns, but 79% of 2nd-person pronouns between 0;11 and 2;6. Rarely, some children consistently reverse pronouns (e.g., Oshima-Takane, 1992) for a period of time before they learn the correct use of the pronominal system. Dale and Crain-Thoreson (1993, p. 576) observed, "cases where children consistently reverse pronouns (such as Oshima-Takane's subject) seem relatively rare. More typical is an intermittent, low frequency pattern of errors." Thus, when pronoun reversals occur in typical development, they are usually inconsistent and occur at a low frequency.

### Atypical development

Most studies have found that speaking children with ASD reverse pronouns at a higher frequency than TD children, though the specific frequencies found by individual scholars have varied. With respect to the percentage of hearing children with ASD who produce pronoun reversals, studies have ranged on the low end from just one of 38 children (2.6%) with ASD at age 4 (Barokova and Tager-Flusberg, 2020), to 7 of 11 such children (63.6%; Kanner, 1943) on the high end, with other reports falling somewhere in the middle: Lee et al. (1994) reported reversals in 3 of 25 adolescents (12%) with ASD ages 14–17, while Jordan (1989) reported reversals in 3 of 11 children (27.3%) with ASD between the ages of 6;8–16;5.

Shield et al.'s (2015) study is the only study to-date on signed pronouns produced by signing children with ASD. This study had both a naturalistic and an elicited (experimental) component. ASL pronouns produced during naturalistic observation were analyzed in their discourse contexts by independent raters in order to identify potential pronoun reversals. Two possible examples were identified, both in echolalic contexts. In neither case was it clear that the child had intended to refer to either himself or the investigator, as he tended to echo most utterances and had very low receptive language skills overall. In the elicited pronoun task of the same study, none of the 15 native-signing children with ASD from whom ASL pronouns were elicited produced any reversed forms, suggesting that pronoun reversals in ASL may not occur as frequently as they do in spoken languages.

In studies that were either case studies or reported total frequency of pronoun reversal across the samples, we also find a range of frequencies. Naigles et al. (2016) reported that the 15 children with ASD in their sample reversed 6.4% of pronouns between 2;6–3;6, which decreased to 4.15% of pronouns between 3;9–4;6. Several other studies have found higher frequencies of pronoun reversals: Evans and Demuth (2012) reported that their case-subject with ASD reversed 13% of 1st-person pronouns and 79% of 2nd-person pronouns between ages 0;11 and 2;11, while Tager-Flusberg (1994) found that 13.2% of all personal pronouns were reversed by six children with ASD ages 3–10 years.

Thus, most studies have found that, when children with ASD produce pronoun reversals, they do so at relatively low frequencies, and are rarely consistent in producing reversals. In comparison with TD children, children with ASD appear to produce a higher rate of pronoun reversals (e.g., 6.4% of total pronouns at ages 2;6–3;6 for children with ASD compared to <1% of total pronouns between 2;9–3;3 for TD children; Naigles et al., 2016).

## Which cognitive skills are implicated in the production of pronoun reversals?

### Typical development

Several studies have found that pronoun reversals are produced by TD children when their language development has outpaced their social, cognitive, or pragmatic development. Evans and Demuth (2012) attributed pronoun reversals to precocious talkers who had not yet mastered the deictic (perspective-taking) nature of the pronominal system. Petitto (1987) had a similar interpretation of the two signing children she observed, who seemingly treated indexical points as frozen lexical signs, echoing Clark's (1978) hypothesis that very young children may assume that pronouns function like names with fixed referents. Similarly, Dale and Crain-Thoreson (1993, p. 581) observed that their pronoun "reversers appear to be somewhat more advanced grammatically [than non-reversers]: their grammatical morpheme index is significantly higher, and their MLU is higher, though non-significantly, than those of the non-reversers." The development of social-cognitive skills such as perspective-taking and theory of mind (ToM) have been shown to support the proper use of pronouns: for example, Loveland (1984) found that children who showed evidence of perspective-taking ability did not reverse pronouns. In line with these studies, Overweg et al. (2018, p. 228) concluded that ToM understanding "was associated with correct pronoun interpretation in older TD children relative to younger TD children, … indicat[ing] that pronoun reversals most likely result from perspective-shifting difficulties." Finally, some have theorized that pronoun reversals could result from heavy cognitive load in complex situations, even when children understand perspective-taking (Dale and Crain-Thoreson, 1993). Thus, when pronoun reversals occur in typical development, they appear to result from a mismatch between the rate of development of language and the social or cognitive skills that are needed to understand and produce deictic forms.

### Atypical development

Pronoun reversals in children with ASD have been attributed to various causes, including echolalia, delayed language development, intellectual and cognitive deficits, and pragmatic difficulties. Kanner (1943) believed that pronoun reversals were the result of echolalia, and others have made similar claims, such as that reversed pronouns are produced because children with ASD repeat rote phrases they have heard from others (Ricks and Wing, 1975). Unlike precocious TD children, delayed language development has been implicated in the production of pronoun reversals by children with ASD (Tek et al., 2014), specifically low MLU (Chiat, 1982; Loveland and Landry, 1986; Dale and Crain-Thoreson, 1993) or syntactic difficulties (Tager-Flusberg, 2006; Eigsti et al., 2007). Other reports find a connection with intellectual disability (Kanner, 1943; Tager-Flusberg, 1994), perspective-taking skills involving theory of mind (Meir and Novogrodsky, 2019), or difficulties with pragmatics, specifically understanding how pronominal forms shift reference between speakers in discourse (e.g., Charney, 1980; Hobson, 1990; Tager-Flusberg, 1996; Hobson et al., 2010; Mazzaggio and Shield, 2020). Pronoun reversals may also arise through the interaction of multiple factors in development, specifically when language outpaces social development (Evans and Demuth, 2012). For example, Naigles et al. (2016) found that children with ASD who produced more pronoun reversals than TD children also had lower joint attention scores, whereas children with ASD who had higher vocabulary and joint-attention scores produced fewer pronoun reversals in imitative contexts, thus implicating both language and social abilities in producing pronoun reversals.

In sum: pronoun reversals are produced by very young TD children (usually before 2;6) and older children with ASD into adolescence; they are produced relatively infrequently, accounting for under 10% of pronouns produced by children with ASD, and they are produced by children whose social cognition lags behind their language development, or by children with echolalia or language impairment.

In the next section we will review what is currently known about the occurrence of palm orientation reversals in signing children.

## Palm orientation reversals in signing children

To date, there are two reports of palm orientation reversals produced by signing children with ASD: Shield and Meier (2012) studied five native-signing children with ASD (four deaf children and one hearing child of Deaf adults) ranging in age from 4;6 to 7;5 and Shield et al. (2020) published a longitudinal case study of a single native signer with ASD over the span of 10 years, from age 4;11 to 14;11.

 

Shield and Meier (2012) described two studies: naturalistic observation and elicited fingerspelling. During observation of spontaneous interactions between three children with ASD and their Deaf parents, Child 1 (age 7;5) produced 50 fingerspelled letters with the palm orientation facing inward rather than outward. Child 2 (age 4;6) produced three lexical signs (the number signs SIX, SEVEN, and EIGHT) with inward palm orientation rather than outward, and Child 3 (a hearing children of deaf adults aged 6;6) produced the handwave gesture and the lexical sign FLASHING-LIGHT with an inward rather than outward palm orientation. The fingerspelling task looked at four native-signing children with ASD; three of these children (ages 5;8, 6;6, and 7;5) reversed the palm orientation of 72 of 179 (40.2%) fingerspelled letters such that the children's palm faced toward their own body rather than outward. None of the control group of 12 typical deaf children (ages 3;7–6;9) produced any such palm orientation reversals. The three children with ASD who made such errors had lower parent-reported language scores on the Language Proficiency Profile-2 (LPP-2; Bebko et al., 2003) than those children who did not make such errors, including the 12 typical deaf children and the child with ASD who did not make any palm reversals. This significant difference suggests that children with lower receptive and expressive language skills may be more prone to making such errors.

In the later case study, Shield et al. (2020) described the signing of a single native-signing child with ASD, a left-handed hearing male who is the child of two Deaf parents. They analyzed his signing at ages 4;11, 6;6, 10;2, and 14;11, reporting that while his signing improved consistently in terms of handshape, location, and movement, the error rate in palm orientation remained high, reaching over 50% of all signs produced at age 14;11. They distinguished between midline errors (i.e., palm orientation errors in which the palm is oriented toward the midline rather than facing inwards or outwards), which could be attributed to motor challenges (since the palms face the midline in the resting position of the arms), and 180-degree reversal errors, which are unlikely to be produced due to motor issues and are more likely due to differences in imitation. The child produced a total of 82,180-degree reversal errors over the four data collection sessions (one at age 4;1, 15 at age 6;6, 8 at age 10;2, and 58 at age 14;11); all but five of these reversals were produced on fingerspelled letters, with the remainder being produced on lexical signs. For this child as well as the children described in Shield and Meier (2012), the palm reversals on lexical signs cannot be attributed to coarticulation effects because the signs were produced in isolation as single signs. Even at age 14;11, the participant produced 180-degree reversal errors on 58 of 112 total palm orientation errors (51.8%), providing the first indication that palm orientation errors can persist into adolescence for some signers with ASD.

Thus, there is evidence that some children with ASD produce palm orientation reversals, while TD signing children do not appear to do so, at least not at the ages studied. Furthermore we have preliminary indication that such reversals can persist into adolescence. However, what is currently unknown is how frequently such reversals tend to occur, at what ages, whether or not they occur in typical development, and if signers who produce such reversals share a particular linguistic or cognitive profile. Such information would be useful in order to establish a comparison between palm reversals and pronoun reversals. However, we should caution from the outset that, given the wide age ranges and relative infrequency of both phenomena, our conclusions must be considered preliminary. Still, a clearer characterization of the palm reversal phenomenon in particular would help bring potential comparisons into focus.

In order to better understand the occurrence of palm orientation reversals in child development, the study that follows probes the frequency with which palm orientation reversals are produced by signing children with and without ASD. The study will help us to understand the cognitive and linguistic profiles of children who produce such reversals, and whether or not palm reversals are appropriately considered a sign-language analog to pronoun reversals in speech.

# Materials and methods

## Participants

The participants in this study have been described in several prior publications (Shield et al., 2015, 2016, 2017; Bhat et al., 2016); however, the tasks described in this paper have not previously been analyzed for palm orientation. For the current study, we included two groups of participants: (1) native-signing children with ASD ($N = 17$; four females; age range 5;0–14;4; mean age 9;10) and (2) a control group of native-signing Deaf children who are typically-developing ($N = 24$; 14 females; age range 6;1–12;9; mean age 8;10). All of the children were themselves deaf except for two hearing children of Deaf adults in the ASD group, participants M7 and M17.

Three of the children who participated in Shield and Meier's (2012) preliminary fingerspelling study reported on above also participated in this study (approximately 5 years later). Child 1, aged 7;5 in the earlier study, is referred to here as M8, and was tested at age 12;7; Child 3, aged 6;6 in the earlier study, is referred to here as M7, and was tested at age 10;2; and Child 4, aged 5;8 in the earlier study, is referred to here as M4, and was tested at age 9;8.

## Assessments

All participants were administered a battery of tests in order to gather information regarding their nonverbal intelligence, linguistic abilities, and social skills. In order to assess nonverbal intelligence, the Test of Nonverbal Intelligence, Fourth Edition was administered (TONI-4; Brown et al., 2010). To assess receptive competence in ASL, the American Sign Language Receptive Skills Test (ASL RST; Enns et al., 2013) was administered. The TONI-4 and ASL RST use standard scores (SS), which have a mean score of 100 and a standard deviation of 15. Scores between 85 and 115 are considered to lie within normal limits.

ASD diagnosis was confirmed *via* the Autism Diagnostic Observation Schedule, Second Edition (ADOS-2; Lord et al., 2012). Only the participants with ASD were administered the ADOS-2. The Social Communication Questionnaire (SCQ; Rutter et al., 2003) was completed by the parents of all participants in order to ensure that participants in the control group were not above threshold for ASD risk.

Finally, two experimental tests were administered in order to assess social competence. A minimally-verbal test of theory of mind (ToM), specifically false-belief, involved the participants being given picture cards sequenced to tell a story based on Wimmer and Perner's (1983) unseen-displacement task. Participants were tasked with identifying the appropriate ending from a choice of two picture cards (as described in Shield et al., 2016). A minimally-verbal test of visual perspective-taking (VPT) tasked participants with matching their own perspective or the perspective of the experimenter, who was seated across the table, to a three-dimensional toy on a turntable between them (as described in Shield et al., 2016). ToM and VPT were measured in four trials each and reported as overall accuracy proportions out of four, with overall scores ranging from zero to one. The scores on each of these assessments for all participants are reported in Table 1 below.

Although the children in the two groups did not differ statistically in chronological age or nonverbal intelligence, the groups differed significantly in receptive language abilities, ToM, and VPT. Specifically, the TD group had significantly higher receptive language, ToM, and VPT scores. The ASD group had significantly higher SCQ scores than the control group, and all of the TD participants scored under the threshold score for ASD risk on the SCQ (=11).

## Procedure

We used a fingerspelling task to elicit signs because palm orientation errors have surfaced most often in fingerspelling although such errors have also been documented in lexical signs (Shield and Meier, 2012). For example, fingerspelling accounted for 110 of the 112 (98.2%) palm orientation errors produced by the child described by Shield et al. (2020) at age 14;11. Fingerspelled letters are produced in neutral space in front of the signer's body and, with the exception of the letters G, H, P, and Q, are typically produced with the palm of the signer facing outward towards an interlocutor; see Figure 1. Thus, fingerspelled letters provide many opportunities for reversal, having a specified palm orientation (outward for all letters except G and H, which face inward, and P and Q, which face downward) and lacking an anchor to the signer's body, which could attenuate reversal.

Deaf parents sometimes include fingerspelled words in their signing to their very young deaf children (e.g., as early as 2 months old; Kelly, 1995), and sign-exposed children learn to fingerspell very early on, with some children producing fingerspelled words as early as age two (Kelly, 1995; Erting et al., 2000). Padden (1991) has explained that deaf children "learn to fingerspell twice": that is, they first learn to produce fingerspelled words as if they were lexical signs, and later they learn to connect these signs to written English words. Thus, the ability to fingerspell emerges naturally as children acquire ASL, but only later is fingerspelling explicitly linked to written representations. As all of the children in our study were school-age, we determined that presenting written English words as stimuli for fingerspelling would be an appropriate format.

The following lowercase written words were presented by the lead author, a hearing late learner of ASL, to each of the participants on a tablet: *ball, paper, girl, school, bird, teach, phone, desk, chair, table, doll, father, mother, van,* and *bug*. Thus, participants had the opportunity to produce 69 individual fingerspelled letters in these English target words. The participants were presented with each of the stimulus words one at a time and were instructed to fingerspell each word that appeared on the screen. The participants were able to view the written English words on the tablet screen while fingerspelling, thus eliminating any demands on working memory. Once the word was fingerspelled, the investigator presented the next word. Participants completed this task independently without feedback; any deviations from accurate spelling or correct handshape production were not corrected by the investigator.

## Coding

Using ELAN (EUDICO Linguistic Annotator; Tacchetti, 2017) multimodal coding software, each handshape produced was coded for its alphabetic label (A, B, C, etc.) and the palm orientation of each signed letter was coded as *inward* (facing the signer's body), *outward* (facing away from the signer's body), *upward* (facing the ceiling), *downward* (facing the floor), or *midline-facing* (facing toward the signer's midline; i.e. towards the

TABLE 1 Group mean scores and standard deviations on assessments.

| Group | Age (SD) | TONI SS (SD) | ASL RST SS (SD) | SCQ (SD) | ToM (SD) | VPT (SD) |
|---|---|---|---|---|---|---|
| ASD (N = 17) | 9.82 (2.76) | 96.94 (12.18) | 90.71 (12.36) | 14.29 (6.80) | 0.58 (0.37) | 0.30 (0.44) |
| TD (N = 24) | 8.86 (1.83) | 103.92 (12.09) | 109.29 (6.73) | 2.67 (2.73) | 0.82 (0.24) | 0.64 (0.43) |
| *p*-value | 0.60 | 0.08 | ** < 0.001 | ** < 0.001 | *0.03 | *0.02 |

*$p<0.05$ and **$p<0.001$.

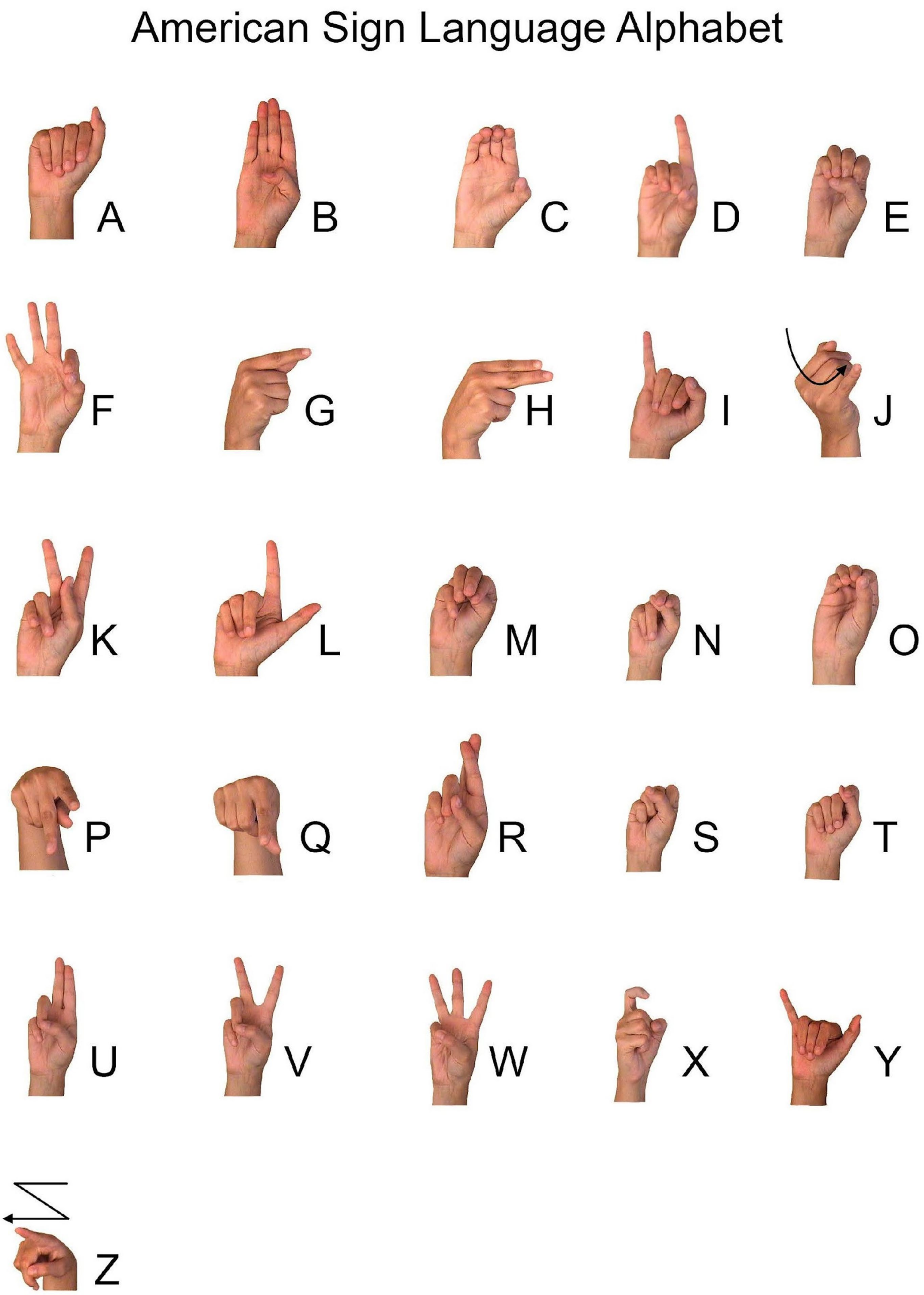


FIGURE 1
Handshapes of the ASL Fingerspelling Alphabet. ASL alphabet image freely available from StartASL.com, copyright © 2008 StartASL.com.

left for a right-handed signer or towards the right for a left-handed signer). Each palm orientation value was scored as being produced *correctly* or as an *error* based on standard citation forms. Errors were classified as *reversal errors* (substitutions of inward orientation for outward and vice versa), *midline errors* (for midline-facing orientations), or *other errors* (upward or downward orientations, except for P and Q, which have downward-facing orientations in their citation forms).

While producing the fingerspelled letters C and O with a midline-facing orientation is widely accepted within signing communities, for the sake of consistency, these letters were coded as *midline* errors if produced midline-facing. Similarly, the production of P with a midline-facing or even a slightly inward-facing palm orientation reflects variation seen among native signers (Geer, 2016). For the purposes of our analyses, these errors were coded as *midline* errors for midline-facing productions, or *other* errors for inward-facing productions, but were not coded as palm reversal errors, as these variants are used among native signers (Geer, 2016).

In addition to palm orientation errors, we also coded how accurately the participants were able to spell the written word (i.e., spelling errors). Fingerspelled letters were coded as spelling errors if the handshape produced represented a letter that does not appear in the target English word or if it was produced in a different order from the target English word. False starts (e.g., C-H-C-H-A-I-R for "chair") were not coded as errors if the word was ultimately spelled correctly; neither were double/single letters (e.g., D-O-L for "doll") coded as errors since it is acceptable in ASL fingerspelling to produce a double letter just once, with a slight hold.

## Reliability

To ensure the reliability of the coding system, each video was coded by a second and third trained coder experienced in the coding of ASL. Differences in coding were discussed by the coders and disagreements were resolved through consensus. The main coder then adjusted the rest of the coding to reflect the decisions made through consensus discussion with the additional coders.

# Results

We examined all of the fingerspelled letters produced by both groups and calculated the number of letters that were produced with the three kinds of palm orientation errors. The total number of fingerspelled letters produced by the two groups differed because there were different numbers of children in each group and because individual children produced different numbers of fingerspelled letters, usually due to spelling errors or repeated fingerspelling attempts. All fingerspelled letters were coded, regardless of the number of times the child attempted to spell the target word.

The TD group produced a total of 1742 fingerspelled letters, whereas the ASD group produced 1,191. TD children produced an average of 72.6 ($SD = 7.46$) letters whereas the children with ASD produced an average of 70.1 letters ($SD = 15.8$); this difference was not significant; $t$ (39) = 0.69, *ns*. Note that one very young child with ASD (M9, age 5;3) did not complete the task and only produced 12 fingerspelled letters. The ASD group produced more spelling errors (total = 110; $M = 6.5$, $SD = 5.8$) than the TD group (total = 39; M = 1.6, SD = 2.9), $t$ (39) = 3.54, $p = 0.001$. The ASD group also produced more palm reversal errors ($M = 5.12$, $SD = 11.34$) than the control group ($M = 0.46$, $SD = 1.25$), $t$ (39) = 2.02, $p = 0.05$. TD children produced an average of 14.67 midline errors ($SD = 15.89$) whereas the children with ASD produced an average of 14.0 midline errors ($SD = 13.7$); this difference was not significant; $t$ (39) = 0.14, *ns*. TD children produced an average of 5.71 other errors ($SD = 4.91$) whereas the children with ASD produced an average of 4.59 other errors ($SD = 3.74$); this difference was not significant; $t$ (39) = 0.65, *ns*. See Figure 2 for a comparison of the error rates for the three error types. Spelling accuracy was weakly related to the production of palm reversal errors; $r$ (39) = 0.33, $p < 0.05$.

Since the two groups did not differ in their rate of production of midline or other errors, we next examine the reversal errors produced by children from the two participant groups.

## Typically-developing children

Six of the 24 participants in the control group of TD deaf children produced at least one palm reversal error. Five of these six children produced a single error, while one child (F7) produced six palm reversal errors. The palm reversal rate for each TD participant is shown in Table 2 below.

Six of the 11 (55%) palm reversal errors made by the control group, all produced by participant F7, were in-to-out reversals, meaning a letter with a citation form palm-in orientation was produced with an inaccurate palm-out orientation; all were instances of the letter H, which the child produced like the letter U every time the target letter H appeared in a word (with outward-facing palm orientation and fingers oriented vertically rather than horizontally; see Figure 1).[2] The five remaining errors produced by this group were out-to-in errors: two errors on fingerspelled letters directly following the palm-in letter H, one error on the letter E in a word (*phone*) containing the palm-in letter H and two on the letters A and R in the word *paper*. The palm reversal errors produced by this group are found in Table 3 below.

## Participants with ASD

Seven of the 17 participants in the ASD group made at least one palm reversal error, and five of these seven produced two or more palm reversal errors. The palm reversal rate for each participant with ASD is shown in Table 4 below. Three of these participants accounted for the preponderance of the total palm reversals (M7, M8, and M17: 79/87 errors). Five of the 87 palm reversal errors (6%) were in-to-out errors, produced on the two

2 Note that these letters could have been coded as instances of the letter U without palm reversal. In this case, these would constitute errors in the accuracy of representing the printed word, but would not have constituted palm-reversal errors. We have chosen to code these as instances of the letter H, rather than U, due to the consistency of the error.

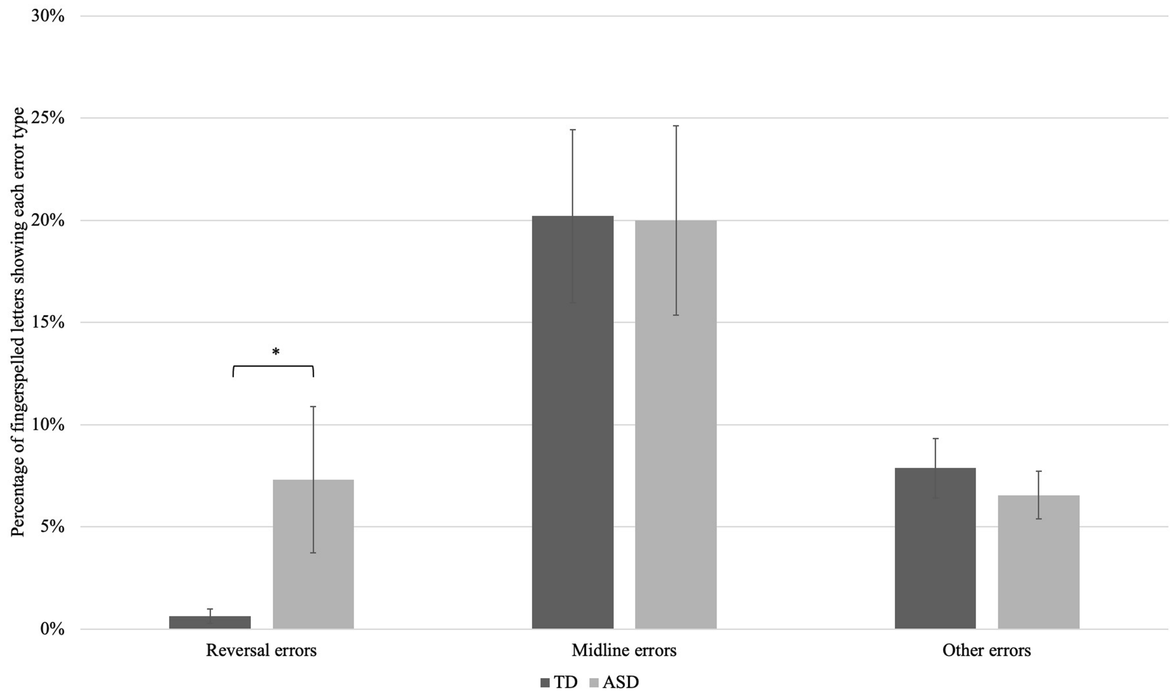


FIGURE 2
Mean error rates, by group, for three types of palm orientation error. Groups did not differ in their rate of production of midline or other errors, but the ASD group made significantly more reversal errors than the TD group, $p=0.05$.

letters whose citation-form palm orientation is palm-in, specifically the letters G (3 tokens) and H (2 tokens). The remaining 82 palm reversal errors (94%) were out-to-in errors. The details of each palm reversal error can be found in Table 5 below.

## Cognitive and linguistic profile of children who reverse

Six of the TD children produced one or more palm reversals, with five producing just a single fingerspelled letter with reversed palm orientation. The five TD children who produced a single palm reversal did not differ from the 18 TD children who produced no palm orientation reversals in chronological age, non-verbal intelligence, ASL receptive language skills, or SCQ scores. However, the one TD child who produced 6 palm orientation reversals (F7) had an SCQ score of 10, just under the threshold score for ASD risk of 11. All other TD children had scores of 7 or under, indicating low risk of ASD.

Given that in the TD group there were five TD children who produced just one palm orientation reversal, we classified the participants with ASD who produced two or more palm reversal errors as "reversers," in contrast with those 12 participants with ASD who produced zero or one palm reversal errors ("non-reversers"). Reversers had lower overall receptive language abilities (as measured by the ASL RST) than non-reversers, $t(15)=-2.81$, $p<0.05$. The reversers and non-reversers did not differ significantly in age, nonverbal intelligence, ASD severity (as indicated by ADOS-2 or SCQ scores), theory of mind, or visual perspective-taking, though note that the TONI (non-verbal IQ) scores of the reversers were nominally lower than the non-reversers, and the reversers were nominally older than the non-reversers. Group means are reported in Table 6 below. We also include box-and-whisker plots of the reversers and non-reversers in terms of ASL RST scores, TONI standard scores, and chronological age in order to better visualize the distribution of data for the two groups (Figure 3).

## Phonetic context of reversals

Shield et al. (2020) posited that palm orientation errors could be rooted in motoric factors or in differences in imitation strategy. They established that fingerspelled letters oriented towards the midline (rather than clearly outward or inward) could be the result of underarticulation, and thus motoric in origin. Both TD children and children with ASD in this study produced midline palm orientation errors, as shown in Figure 2.

Shield et al. further hypothesized that palm orientation reversals produced during spontaneous signing could reflect the effects of a "visual matching" imitation strategy employed during learning in which the child produces signs as they appear from the child's perspective. However, it is also possible that some palm

TABLE 2 Typically-developing children: Palm reversal rates on fingerspelled letters.

| Participant ID | Age (years; months) | *N* of palm reversals/Total fingerspelled letters | Reversal rate |
|---|---|---|---|
| F1 | 8;7 | 0/66 | 0.0% |
| F2 | 7;7 | 0/67 | 0.0% |
| F3 | 7;7 | 0/79 | 0.0% |
| F4 | 10;3 | 1/53 | 1.9% |
| F5 | 9;7 | 0/69 | 0.0% |
| F6 | 6;7 | 0/73 | 0.0% |
| F7 | 6;6 | 6/74 | 8.1% |
| F8 | 11;2 | 0/86 | 0.0% |
| F9 | 11;6 | 0/75 | 0.0% |
| F10 | 7;7 | 0/68 | 0.0% |
| F11 | 7;7 | 1/76 | 1.3% |
| F12 | 8;9 | 0/74 | 0.0% |
| F13 | 8;5 | 0/77 | 0.0% |
| F14 | 9;3 | 1/67 | 1.5% |
| M1 | 8;10 | 0/84 | 0.0% |
| M2 | 7;9 | 0/73 | 0.0% |
| M3 | 9;11 | 0/68 | 0.0% |
| M4 | 9;7 | 1/69 | 1.4% |
| M5 | 8;7 | 0/77 | 0.0% |
| M6 | 12;2 | 0/77 | 0.0% |
| M7 | 12;9 | 0/69 | 0.0% |
| M8 | 9;11 | 0/65 | 0.0% |
| M9 | 6;1 | 0/69 | 0.0% |
| M10 | 6;3 | 1/87 | 1.1% |
| | | Total = 11/1742 | 0.6% |

reversals could be due to coarticulation; that is, due to adjacency to another fingerspelled letter with the opposite palm orientation. As laid out above, there are four fingerspelled letters in the ASL alphabet that differ in palm orientation from all of the others: G and H (which have an inward-facing palm orientation) and P and Q (which face downward). All other fingerspelled letters face outward from the signer. We thus examined the phonetic context in which reversal errors were produced in order to determine if coarticulation could be responsible for the reversals.

For the TD participants, we exclude subject F7's six productions of H as U, inasmuch as she produced this form in every word that included the letter "h." Of the remaining five reversals, three occurred immediately after the letters P or H: subject F11 reversed the letter A in "paper"; subject F4 reversed the letter A in "chair," and subject F14 reversed the letter E in "father." It is plausible that each of these reversals occurred due to assimilation to the palm orientation value of the previous handshape. The other two reversals produced by TD children occurred word-finally: the letter R in "paper" by subject M4 and the letter E in "phone" by subject M10. Although the motivation for these reversals is less clear, each of the reversals occurred in words in which the letters P or H also appeared, raising a question of whether the palm orientation specification could spread across non-adjacent segments.

For the participants with ASD, 12 of the 87 palm reversals can be explained by adjacency to the letter H. Subject M7 produced inward palm orientation on the letter C in the words "school" (misspelled "shchool") and "teach" (produced as "teteach"), on the letters O-N-E in the word "phone" (spelled "pphone"), on the letter A in the word "chair," and on the letters T and E in the word "mother." In two instances, the occurrence of H appears to have triggered the spreading of inward-facing orientation across the

TABLE 3 Typically-developing children: Fingerspelling errors.

| Stimulus | Participants | | | | | |
|---|---|---|---|---|---|---|
| | F4 | F7 | F11 | F14 | M4 | M10 |
| ball | B-A-L-L-B-A-L | B-A-L-L | B-A-L-L | B-A-L | B-A-L-L | B-A-C-L-L |
| paper | – | P-A-P-E-R | P-**A**-P-E | P-A-P-E-R | P-A-P-E-**R** | P-A-P-E-P-A-P-E-R |
| girl | – | G-I-R-L | G-I-R-L | G-I-R-L | G-I-R-L | G-I-R-L |
| school | – | S-C-**H**-O-O-L | S-C-H-O-O-L | S-C-H-O-L | S-C-H-O-O-L | S-C-H-O-O-L |
| bird | – | B-I-R-D | B-I-R-D | B-I-R-D | B-I-R-D | B-I-R-D |
| teach | T-E-A-C-H | T-E-A-C-**H** | T-E-A-C-H | T-E-A-C-H | T-E-A-C-H | D-L-T-O-E-A-C-H |
| phone | P-H-O-N-E | P-**H**-O-N-E | P-H-O-N-E | P-H-O-N-E | P-H-O-N-E | P-H-O-N-**E** |
| desk | D-E-S-K | B-D-E-S-K | D-E-S-K-D-E-S-K-D-E-S-K | D-E-S-K | D-E-S-K | D-E-S-D-K |
| chair | C- H-**A**-I-R | C- **H** A-L-R | C-H-A-I-R | C-H-A-I-R | C-H-A-I-R | C-H-A-H-A-I-R |
| table | T-A-B-L-E | T-A-B-L-E | T-A-B-L-E | T-A-B-L-E | T-A-B-L-E | T-A-B-L-E |
| doll | D-O-L-L | B-O-L-L | D-O-L-L | D-O-L-L | D-O-L-L | B-O-O-L-B-O-O-L |
| father | F-A-T-H-E-R | R-T-E-F-A-T-**H**-E-R | F-A-T-H-R | F-A-T-H-**E**-R | F-A-T-H-E-R | F-A-T-H-E-R |
| mother | M-O-T-H-E-R | M-O-T-**H**-E-R | M-O-T-H-E-R | M-O-T-H-E-R | M-O-T-H-E-R | M-O-L-T-H-E-R |
| van | V-A-N | V-A-N | V-A-N | V-A-N | V-A-N | V-W-V-A-N |
| bug | B-U-G | B-N-U-G | B-B-U-G | B-U-G | B-U-G | D-U-G |
| Total fingerspelled letters | 53 | 74 | 76 | 67 | 69 | 87 |
| Total palm reversal errors | 1 (1.9%) | 6 (8.1%) | 1 (1.3%) | 1 (1.5%) | 1 (1.4%) | 1 (1.1%) |

Letters produced with a 180-degree palm reversal error are bolded. Letters whose citation-form palm orientation is palm-in are underlined.

rest of the word; both M7's production of "phone" and M8's production of "chair" (misspelled "chardir") contained reversals on each of the fingerspelled letters that occurred subsequent to the H.

TABLE 4 Children with ASD: Palm reversal rates on fingerspelled letters.

| Participant ID | Age (years; months) | *N* of palm reversals/Total fingerspelled letters | Reversal rate |
|---|---|---|---|
| F1 | 14;4 | 0/69 | 0.0% |
| F4 | 13;3 | 1/68 | 1.5% |
| F5 | 9;6 | 0/75 | 0.0% |
| F6 | 11;1 | 0/86 | 0.0% |
| M1 | 8;5 | 1/80 | 1.3% |
| M2 | 9;5 | 4/71 | 5.6% |
| M3 | 11;3 | 0/69 | 0.0% |
| M4 | 9;8 | 0/69 | 0.0% |
| M5 | 9;6 | 0/78 | 0.0% |
| M6 | 9;0 | 0/68 | 0.0% |
| M7 | 10;2 | 10/75 | 13.3% |
| M8 | 12;7 | 34/79 | 43.0% |
| M9 | 5;3 | 0/12 | 0.0% |
| M10 | 11;10 | 2/70 | 2.9% |
| M12 | 5;1 | 0/73 | 0.0% |
| M17 | 12;6 | 35/75 | 46.7% |
| M19 | 5;0 | 0/74 | 0.0% |
| | | Total = 87/1191 | 6.7% |

The opposite effect also appeared in our data: rather than the spreading of inward-facing palm orientation onto segments that are typically produced with outward-facing orientation, we also observe the spreading of outward-facing orientation onto segments that are typically produced with inward-facing orientation. These examples include the H in "phone" produced by subject M1, the G in "girl" produced by subject M2, the G in "girl" (misspelled "gierl") by subject M10, and the H in "father" produced by subject M10. We also find two instances of word-final reversals: the R in "mother" (misspelled "moter") by subject F4 and the R in "paper" produced by subject M7.

Importantly, there were at least 64 reversal errors produced by children with ASD that cannot be explained by adjacency. Some words that did not contain G, H, P or Q nonetheless contained reversal errors: these included the V in "van" produced by subject M2, all four letters in the word "desk" produced by subject M8, each letter in the word "table" (misspelled "tadile") by subject M8, all three letters in the word "van" produced by subject M8, all four letters in the word "ball" produced by subject M17, all four letters in the word "bird" produced by subject M17, each of the letters except the initial letter in "desk" (misspelled "deask") by subject M17, and each of the letters in the word "table" (misspelled "tabitable") by subject M17.

## Longitudinal data

This study included three participants whose fingerspelling had been analyzed in Shield and Meier's (2012) preliminary study

TABLE 5 Children with ASD: Fingerspelling errors.

| Stimulus | Participant | | | | | | |
|---|---|---|---|---|---|---|---|
| | F4 | M1 | M2 | M7 | M8 | M10 | M17 |
| ball | B-A-L-L | B-A-L-L | B-A-L-L | B-A-L-L | B-A-E-L | B-A-L-L | **B-A-L-L** |
| paper | P-A-P-E-R | P-A-P-E-R | P-A-P-E-R | P-A-P-E-**R** | P-A-P-E-R | P-A-P-E-R | P-**A**-P-**E-R** |
| girl | G-I-R-L | G-I-R-L | **G**-I-R-I | G-I-R-L | G-I-I-R-L | **G**-I-E-R-L | G-I-R-L |
| school | S-C-H-O-L | S-C-H-O-O-L | S-C-N-O-O-I | S-H-**C**-H-O-O-L | S-C-U-H-O-O-L | S-C-O-O-L | E-**S-C**-H-O-O-**L** |
| bird | B-I-R-D | B-I-R-D | B-I-R-B | B-I-R-D-L | D-I-R-D | B-I-R-D | **B-I-R-D** |
| teach | T-E-A-C-H | T-E-A-C-H | N-T-E-A-C-N | T-E-T-E-A-**C**-H | C-T-E-A-C-U-H | T-E-A-C-H | **T-E-A-C** |
| phone | P-H-O-N-E | P-**H**-O-N-E | P-R-N-O-N-E | P–P-H-**O-N-E** | Q-H-O-N-A | P-H-O-N-E | G-P-H-O-N-E |
| desk | D-D-E-S-K | D-E-S-K | B-E-S-K | D-E-S-K | **D-E-S-K** | D-E-S-K | D-**E-A-S-K** |
| chair | C-H-A-I-R | C-H-A-C-H-A-I-R-C-H-A-I-R | C-N-A-I-R | C-H-**A**-I-R | C-H-**A-R-D-I-R** | C-H-A-I-R | C-H-A-**I-R** |
| table | T-A-B-L-E | T-A-B-L-E | T-A-B-I-E | T-A-B-L-E | **T-A-D-I-L-E** | T-A-B-L-E | **T-A-B-I-T-A-B-L-E** |
| doll | D-O-L-L | D-O-L-L | B-O-I-I | D-O-L | **D**-O-**L** | D-O-L-L | D-O-L-L |
| father | F-A-T-H-E-R | F-A-T-H-E-R | F-A-T-N-E-R | D-F-A-T-H-E–**E**-R | **R-F-A-T**-H-**E-R-R** | F-A-T-**H**-E-R | F-**A**-**T**-H-E-R |
| mother | M-O-T-E-**R** | M-O-T-H-E-R | M-O-T-N-E-R | M-O-**T**-H-**E**-R | **A**-O-**T**-H-**E-R** | M-O-T-H-E-R | M-O-T-H-E-R |
| van | V-A-N | V-A-N | **V**-A-N | W-V-A | **V-A-N** | V-A-N | V-A-N |
| bug | B-U-G | B-G-U-B-U-G | B-**U-G** | B-U-G | **B-U-A**-G-H | B-U-S-G | B-U-G |
| Total fingerspelled letters | 68 | 80 | 71 | 75 | 79 | 70 | 75 |
| Total palm reversal errors | 1 (1%) | 1 (1%) | 4 (6%) | 10 (13%) | 34 (43%) | 2 (3%) | 35 (47%) |

Letters produced with a 180-degree palm reversal error are bolded. Letters whose citation-form palm orientation is palm-in are underlined.

TABLE 6 Children with ASD: Characteristics of reversers versus non-reversers.

| Group | Age | TONI | ASL RST | ADOS severity | SCQ | ToM | VPT |
|---|---|---|---|---|---|---|---|
| Reversers ($N=5$) | 11.13 (1.40) | 89.40 (14.31) | 79.80 (11.86) | 6.60 (1.95) | 15.40 (10.36) | 0.40 (0.45) | 0.40 (0.55) |
| Non-Reversers ($N=12$) | 9.28 (3.04) | 100.08 (10.23) | 95.25 (9.72) | 5.18 (2.60) | 13.83 (5.24) | 0.66 (0.32) | 0.25 (0.40) |
| *p*-value | 0.11 | 0.18 | *0.04 | 0.25 | 0.76 | 0.29 | 0.60 |

*$p<0.05$.

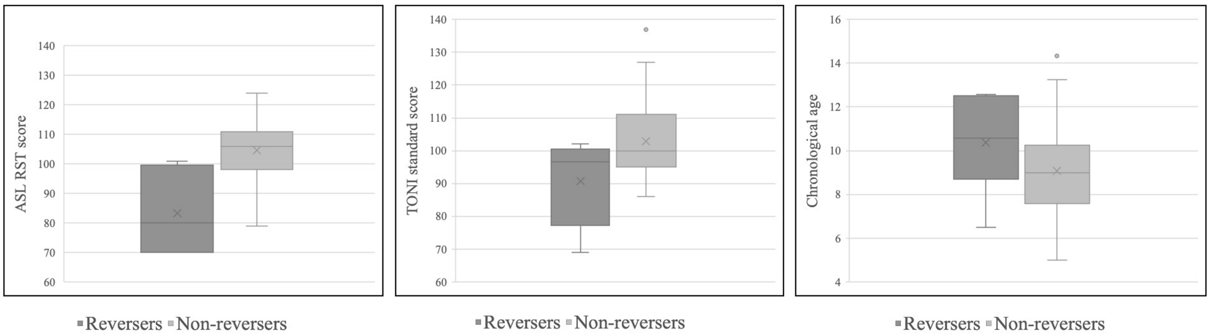


FIGURE 3
Box-and-whisker plots for reversers and non-reversers in terms of ASL RST scores (left), TONI standard scores (center), and chronological age (right).

on fingerspelling. Comparing their performance in this study to the previous study is instructive insofar as it can provide additional information about the developmental trajectory of palm orientation reversals. See Table 7 for information about the ages at which these three participants were tested, intelligence, language, and ASD severity scores, as well as proportion of reversed fingerspelled letters in both studies.

While all three of these participants produced reversals in their fingerspelling data in the prior study (Shield and Meier, 2012), only two, M7 and M8, continued to do so in this study. Subject M8 produced a similar proportion of fingerspelled letters with reversed orientation at both ages, while Subject M7 produced fewer letters with reversed palm orientation in this study (10/75) than in the earlier study (26/43). Subject M4, who produced 19 reversed-orientation letters in the earlier study, no longer produced any palm orientation reversals in this study.

## Discussion

The purpose of this study was to explore the variation in palm orientation of fingerspelled letters produced by native-signing children with and without ASD. Once we identified which children with ASD produced palm reversal errors, we analyzed and compared their cognitive and linguistic profile to that of the children with ASD who did not frequently produce palm reversal errors as well as to a control group of TD deaf children.

As expected, signing children with ASD produced significantly more palm reversal errors than TD signing children. Overall, the participants with ASD produced palm reversal errors on an average of 6.7% of fingerspelled letters, a palm reversal error rate much lower than that found by Shield and Meier's (2012) fingerspelling study, which reported a reversal rate of 40.2% by four native-signing children with ASD. The current study included a much larger sample of signing children with ASD ($N=17$), which may be more representative of the overall population of signing children with ASD. The TD participants in our study produced palm reversal errors on just 0.6% of fingerspelled letters overall, a significantly lower rate than that of the participants with ASD. Most of the palm reversals produced by the TD participants could be attributed to idiosyncratic individual factors (for the U-H substitutions produced by TD participant F7) or to phonetic context, whereas many of the palm reversals produced by the ASD group could not be explained by either of these factors. Only a subset of participants with ASD ($n=7$) produced one or more palm reversal errors, with individual reversal rates of these participants ranging from 1.3 to 46.7% of all letters produced. Three of the children with ASD in particular accounted for the preponderance of palm reversal errors in the ASD group (79/87 errors). The five participants who reversed two or more fingerspelled letters were found to have significantly lower receptive language abilities in comparison to the participants with ASD who produced one or no palm reversal errors. There were no statistically significant differences between the reversers and non-reversers with respect to age, ASD severity, theory of mind, or visual perspective-taking skills.

TABLE 7 Longitudinal analysis: three children participated in Study 1 (Shield and Meier, 2012) and Study 2 (the current study).

| Subject ID Study 1/ Study 2 | Study 1: Age | Study 1: No. of finger-spelled letters with reversed palm | Study 2: Age | Study 2: No. of finger-spelled letters with reversed palm | Study 2: NVIQ SS | Study 2: ASL RST SS | Study 2: ADOS severity |
|---|---|---|---|---|---|---|---|
| Child 1/M8 | 7;5 | 27/57 (47.4%) | 12;7 | 34/79 (43.0%) | 96 | 81 | 6 |
| Child 3/M7 | 6;6 | 26/43 (60.5%) | 10;2 | 10/75 (13.3%) | 69 | 70 | 6 |
| Child 4/M4 | 5;8 | 19/28 (67.9%) | 9;8 | 0/69 (0%) | 117 | 79 | 6 |

## Comparison of palm reversals to pronoun reversals

One goal of this study was to compare the cognitive and linguistic profile of the children with ASD in this study who produce palm reversal errors to the cognitive and linguistic profile of hearing children with ASD who produced pronoun reversals as reported in previous literature. We posited that the two error types have a fundamental similarity in that the forms produced by children involve a type of wholesale or gestalt reproduction of the linguistic form (e.g., production of the word "you" in reference to self in the case of pronoun reversals; production of inward-facing palm rather than outward-facing palm, or vice versa, in the case of palm reversals). We thus speculated that a difference in learning/imitation style in very young TD children and children with ASD could result in different surface phenomena in signed and spoken languages.

Further, we asked if there was evidence that both phenomena occurred:

(a) at similar chronological ages (for both typical and atypical children);
(b) at similar frequencies and with similar (in)consistency within the population of children with ASD;
(c) in children with similar linguistic and/or cognitive profiles, and/or
(d) in individual children with ASD who are bimodal bilinguals in a signed language and in a spoken language.

With regard to point (a), our sample did not include TD children in the age range at which pronoun reversals are reported in the literature (under the age of 2;6). In our sample of signing children with and without ASD, palm reversals were produced throughout the school-age years, with the oldest reverser being 12;6. This included several TD signing children who produced palm reversals, though only one TD child produced more than one reversal error, and this was produced consistently on the letter H and did not spread to other segments. With regard to the children with ASD, the age at which children produced palm reversals is similar to the ages at which hearing children with ASD are reported to produce pronoun reversals in the literature. In particular, several studies on hearing children with ASD have reported pronoun reversals persisting into adolescence (Jordan, 1989; Lee et al., 1994). However, we also find evidence that palm reversals disappear for some children over time: one of the three children who was studied by Shield and Meier (2012) and who produced palm reversals in that study no longer produced palm reversals in the current study, 4 years later. These findings align with the literature on pronoun reversals, which suggests that some children with ASD stop reversing pronouns as development progresses (Kanner, 1943; Naigles et al., 2016).

With regard to point (b), the overall rate of palm reversals in our study (6.7% of fingerspelled letters produced by the children with ASD) is not far from the rate of pronoun reversals produced by speaking children with ASD in some studies in the literature. For example, Naigles et al. (2016) reported a pronoun reversal rate by toddlers with ASD of 7.07% at visit one (when mean age was 31.6 months), averaging 4.15% across all six visits lasting 2 years. Like pronoun reversals, palm reversals are produced inconsistently, even by the children we have labeled as "reversers"; none of the children in our study consistently reversed palm orientation on all fingerspelled segments. As was also reported by Shield and Meier (2012) and Shield et al. (2020), participants with ASD who exhibited a pattern of palm reversal errors did so inconsistently across word contexts. For example, participant M17 in the ASD group produced palm reversal errors on both Ls in the word *ball*, but accurately produced both Ls in the word *doll* with outward palm orientations later in the fingerspelling task. This, too, mirrors the literature on pronoun reversal: hearing children with ASD inconsistently reverse pronouns, such as the six participants in Tager-Flusberg's (1994) study who reversed 13.2% of all of the pronouns in the sample.

Also with regard to point (b), it is clear that palm orientation reversal errors, like pronoun reversals, are produced by a subset of children of ASD. In our sample of native-signing children with ASD, five of the 17 children (29.4%) produced more than one palm reversal (and two additional children produced one palm reversal each, for a total of 41.2% of the sample). The literature reports a wide range of proportions of hearing children with ASD who produce pronoun reversals (2.6%: Barokova and Tager-Flusberg, 2020; 12%: Lee et al., 1994; 27.3%: Jordan, 1989; 63.6%: Kanner, 1943). What is consistent is that it is never the case that every child with ASD within a sample produces pronoun reversals, and our results echo that finding.

With regard to point (c), our study found that palm reversal was most strongly associated with lower receptive language skills within the ASD group, but not within the TD group. There are some resonances between our finding and the literature on pronoun reversals in hearing children with ASD. For example, Naigles et al. (2016) reported that their participants with ASD who produced pronoun reversals had lower vocabulary and joint-attention scores than the participants with ASD who did not produce pronoun reversals. Similarly, the participants in Jordan's (1989) study demonstrated impaired language abilities, with a mean MLU of 2.4 and expressive vocabulary abilities with an age equivalent of 5;7 (despite having an average chronological age of 10;5), as well as intellectual disability, with a mean IQ of 49. The six participants in Tager-Flusberg's (1994) study, too, had an average MLU of 2.24 despite being between the ages of 3 and 10 years old, indicating impaired language abilities.

Finally, with regard to point (d), we did not study the spoken language development of any of the children in our sample, so we cannot comment on whether or not they may produce pronoun reversals in spoken English.

In summary, it seems that hearing children with ASD who produce pronoun reversal errors in their speech tend to exhibit impaired language and/or impaired social cognition. Likewise, the participants with ASD who produced palm reversal errors in our study tended to have lower receptive language abilities when compared to their non-reversing peers. However, there was no significant difference in measures of social cognition between the reversers and non-reversers, at least among the children with ASD (though note that the TD group was significantly better on measures of VPT and ToM). Therefore, at this time, there is not sufficient evidence to support the hypothesis that deficits in social abilities such as ToM could be underlying palm reversal, as was found for pronoun reversal by Naigles et al. (2016).

Nonetheless, pronoun reversals and palm reversal errors appear to share the following characteristics:

- Both error types could reflect a "gestalt" learning style in which children (re)produce linguistic forms without undergoing requisite shifts.
- Both error types are produced more frequently by children with ASD than TD children.
- Both error types are produced by a subset of children with ASD, not all children with ASD.
- Both error types can be produced by children with ASD into (at least) adolescence.
- Both error types may follow a developmental trajectory and disappear over time, for at least some children.
- Both error types are produced relatively infrequently overall.
- Both error types are produced inconsistently by the children who produce them.
- Both error types seem to be associated with impaired language skills within the population of children with ASD.

These similarities are certainly suggestive of parallel phenomena. However, it would be premature to definitively state that palm reversal errors and pronoun reversal errors are analogous phenomena in two different language modalities, for reasons that are explained in the next section.

## Limitations and suggestions for future research

While this study documented a number of similarities between pronoun reversals in speech and palm reversals in sign, there are needed pieces of evidence that are now missing. For example, there is no strong evidence in the literature for palm reversals produced by very young TD deaf children at the ages at which pronoun reversals typically occur in hearing, speaking children (i.e., under the age of 2;6). Indeed, the palm orientation parameter is typically acquired rather early on, especially when compared to the more difficult handshape and movement parameters (Cheek et al., 2001).

Similarly, there is currently only one report of two possible pronoun reversal errors in signers with ASD (Shield et al., 2015), despite a few reports of pronoun reversals produced by four TD signers at very young ages (Petitto, 1987; Jackson, 1989; Pizzuto, 1990). The documentation of pronoun reversals by these young signers would suggest that they may also occur in older signers with ASD. Future studies should continue to document the use of sign-language pronouns by signers with ASD into the school-age years and adolescence. To-date, there is only one report on the use of sign-language pronouns by signers with ASD (Shield et al., 2015); this study found avoidance of pronouns in favor of sign-names or common nouns, but did not document any pronoun reversals.

Future research should further explore the relationships between palm reversal and other aspects of social cognition. While this study found that reversers had lower receptive language skills than non-reversers, there was no strong relationship with difficulties in social cognition, such as in ToM or VPT. Studies of younger deaf children with ASD should document early joint-attention skills in relation to sign-language development in order to better understand how these skills may be related.

The finding of phonetic contexts that may condition palm reversals (such as adjacency to the letters G, H, P, and Q) is unlike anything that has been documented for pronoun reversals in spoken languages. Since palm reversals are a phonetic phenomenon involving one of the parameters of sign articulation, the orientation of the palm can spread to neighboring segments. By contrast, pronouns are individual lexical items, and pronoun reversal involves the substitution of lexical forms rather than phonological values. Even if it is discovered that both phenomena are linked to the same underlying processes, we would not expect the phenomena to behave in exactly the same way, since they function in different areas of language. Relatedly, the cognitive demands of fingerspelling are likely to be quite different from those of producing pronouns in spoken languages, since fingerspelling is tied to letter recognition and literacy. Although working memory is presumably not a constraint on performance in this task (given that participants could view the printed stimulus throughout each trial), children must recognize the printed letter, retrieve the correct fingerspelling handshape from long-term memory, and produce the fingerspelling handshapes in left-to-right order. Indeed, we found a relationship [$r$ (39) = 0.33, $p < 0.05$] between fingerspelling accuracy and palm reversal errors, suggesting that it is possible that palm reversals are largely observed in fingerspelling because fingerspelling places a relatively higher cognitive load on signers than does the production of lexical signs.

Our study was limited to just one aspect of ASL: fingerspelling of English words. Fingerspelling was explored due to the fact that it is an area that has previously been shown to reveal difficulties with palm orientation (e.g., Shield and Meier, 2012; Shield et al., 2020); however, fingerspelling is but a small part of the overall linguistic system of ASL. In comparing the rates of palm reversal errors in our participants with the rates of pronoun reversal errors in the literature on hearing children with ASD, readers are cautioned to take this fact into account.

One particularly promising route for future research could involve bimodal bilinguals with ASD. These are children who are acquiring a signed language and a spoken language simultaneously. It would be particularly compelling, for example, if such children produced pronoun reversals in speech at the same time that they exhibited palm orientation reversals in sign. To date, there are no reports on the signed- and spoken-language development of bimodal bilinguals with ASD (though the longitudinal case study reported by Shield et al. (2020) focused on the signed-language development of a hearing child of Deaf adults). Although this child is a bimodal bilingual, Shield et al. only analyzed his signing (not his speech), so this study does not shed light on whether or not pronoun reversals in speech and palm reversals in sign co-occur in the same individuals. It is also worth noting that two of the three children with ASD who produced the majority of the palm reversals were hearing bimodal bilinguals (M7: 10 reversal errors; M17: 35 reversal errors). Although we do not have reason to believe that the hearing status of these children influenced their production of palm reversals, future research should consider whether the hearing children of Deaf adults may be more susceptible to reversal errors than deaf children of Deaf parents.

## Conclusion

We have presented a study in which we compared palm reversal errors in the fingerspelling of signing children with and without ASD to the phenomenon of pronoun reversals produced by hearing children with and without ASD. There is no question that the two phenomena present some tantalizing similarities which merit more study in the future. Should the two phenomena be more convincingly found to be analogous, they would constitute an interesting example of how the cognitive and social characteristics of ASD yield different linguistic behaviors in the signed- versus spoken-language modalities.

## Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

## Ethics statement

The studies involving human participants were reviewed and approved by Boston University Institutional Review Board. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

## Author contributions

AS designed the study and collected and analyzed the data. MI coded the data and wrote the first draft of the manuscript. AS and RM revised the manuscript. All authors contributed to the article and approved the submitted version.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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# References


Barokova, M., and Tager-Flusberg, H. (2020). Person-reference in autism spectrum disorder: developmental trends and the role of linguistic input. *Autism Res.* 13, 959–969. doi: 10.1002/aur.2243

Bates, E., and Dick, F. (2002). Language, gesture, and the developing brain. *Dev. Psychobiol.* 40, 293–310. doi: 10.1002/dev.10034

Bebko, J. M., Calderon, R., and Treder, R. (2003). The language proficiency profile-2: assessment of the global communication skills of deaf children across languages and modalities of expression. *J. Deaf. Stud. Deaf. Educ.* 8, 438–451. doi: 10.1093/deafed/eng034

Bhat, A. N., Srinivasan, S. M., Woxholdt, C., and Shield, A. (2016). Differences in praxis performance and receptive language during fingerspelling between deaf children with and without autism spectrum disorder. *Autism* 22, 271–282. doi: 10.1177/1362361316672179

Bloom, L., Lightbown, P., Hood, L., Bowerman, M., Maratsos, M., and Maratsos, M. P. (1975). Structure and variation in child language. *Monogr. Soc. Res. Child Dev.* 40, 1–97. doi: 10.2307/1165986

Brown, L., Sherbenou, R.J., and Johnsen, S.K. (2010). *Test of nonverbal intelligence, Fourth Edition*. Pro-Ed, Austin, TX.

Charney, R. (1980). Pronoun errors in autistic children: support for a social explanation. *Int. J. Lang. Commun. Disord.* 15, 39–43. doi: 10.3109/13682828009011369

Cheek, A., Cormier, K., Repp, A., and Meier, R. P. (2001). Prelinguistic gesture predicts mastery and error in the production of early signs. *Language* 77, 292–323. doi: 10.1353/lan.2001.0072

Chiat, S. (1982). If I were you and you were me: the analysis of pronouns in a pronoun-reversing child. *J. Child Lang.* 9, 359–379. doi: 10.1017/S0305000900004761

Clark, E. V. (1978). "From gesture to word: on the natural history of deixis in language acquisition," in *Human growth and development: Wolfson College lectures 1976*. eds. J. S. Bruner and A. Garton (Oxford: Oxford University Press), 85–120.

Dale, P. S., and Crain-Thoreson, C. (1993). Pronoun reversals: who, when, and why? *J. Child Lang.* 20, 573–589. doi: 10.1017/S0305000900008485

Denmark, T., Atkinson, J., Campbell, R., and Swettenham, J. (2014). How do typically developing deaf children and deaf children with autism spectrum disorder use the face when comprehending emotional facial expressions in British sign language? *J. Autism Dev. Disord.* 44, 2584–2592. doi: 10.1007/s10803-014-2130-x

Denmark, T., Atkinson, J., Campbell, R., and Swettenham, J. (2019). Signing with the face: emotional expression in narrative production in deaf children with autism spectrum disorder. *J. Autism Dev. Disord.* 49, 294–306. doi: 10.1007/s10803-018-3756-x

Eigsti, I.-M., Bennetto, L., and Dadlani, M. B. (2007). Beyond pragmatics: Morphosyntactic development in autism. *J. Autism Dev. Disord.* 37, 1007–1023. doi: 10.1007/s10803-006-0239-2

Enns, C.J., Zimmer, K., Boudreault, P., Rabu, S., and Broszeit, C. (2013). *American sign language: Receptive skills test*. Northern Signs Research, Inc., Winnipeg, MB.

Erting, C., Thumann-Prezioso, C., and Benedict, B. (2000). "Bilingualism in a deaf family: fingerspelling in early childhood," in *The deaf child in the family and the school: Essays in honor of Kathryn P*. eds. P. Spencer, C. Erting and M. Marschark (Lawrence Erbaum, Mahwah, NJ: Meadow-Orlans), 41–54.

Evans, K. E., and Demuth, K. (2012). Individual differences in pronoun reversal: evidence from two longitudinal case studies. *J. Child Lang.* 39, 162–191. doi: 10.1017/S0305000911000043

Geer, L.C. (2016). Teaching ASL fingerspelling to second-language learners: Explicit versus implicit phonetic training [doctoral dissertation].

Hobson, R. P. (1990). On the origins of self and the case of autism. *Dev. Psychopathol.* 2, 163–181. doi: 10.1017/S0954579400000687

Hobson, J. A., and Hobson, R. P. (2007). Identification: the missing link between joint attention and imitation? *Dev. Psychopathol.* 19, 411–431. doi: 10.1017/S0954579407070204

Hobson, R. P., Lee, A., and Hobson, J. A. (2010). Personal pronouns and communicative engagement in autism. *J. Autism Dev. Disord.* 40, 653–664. doi: 10.1007/s10803-009-0910-5

Jackson, C. A. (1989). Language acquisition in two modalities: the role of nonlinguistic cues in linguistic mastery. *Sign Lang. Stud.* 62, 1–22.

Jordan, R. (1989). An experimental comparison of the understanding and use of speaker-addressee personal pronouns in autistic children. *Br. J. Disord. Commun.* 24, 169–179.

Kanner, L. (1943). Autistic disturbances of affective contact. *Nerv. Child* 2, 217–250.

Kelly, A. (1995). "Fingerspelling interaction: a set of deaf parents and their deaf daughter," in *Sociolinguistics in deaf communities*. ed. C. Lucas, vol. *1* (Washington, DC: Gallaudet University Press), 62–73.

Lee, A., Hobson, R. P., and Chiat, S. (1994). I, you, me, and autism: an experimental study. *J. Autism Dev. Disord.* 24, 155–176. doi: 10.1007/BF02172094

Lord, C., Rutter, M., DiLavore, P.C., Risi, S., Gotham, K., and Bishop, S.L. (2012). *Autism diagnostic observation schedule, second edition (ADOS-2)*. Western Psychological Services, Torrance, CA.

Loveland, K. A. (1984). Learning about points of view: spatial perspective and the acquisition of I/you. *J. Child Lang.* 11, 535–556. doi: 10.1017/S0305000900005948

Loveland, K. A., and Landry, S. H. (1986). Joint attention and language in autism and developmental language delay. *J. Autism Dev. Disord.* 16, 335–349. doi: 10.1007/BF01531663

Mazzaggio, G., and Shield, A. (2020). The production of pronouns and verb inflections by Italian children with ASD: a new dataset in a null subject language. *J. Autism Dev. Disord.* 50, 1425–1433. doi: 10.1007/s10803-019-04349-7

Meir, N., and Novogrodsky, R. (2019). Prerequisites of third-person pronoun use in monolingual and bilingual children with autism and typical language development. *Front. Psychol.* 10:2289. doi: 10.3389/fpsyg.2019.02289

Naigles, L. R., Cheng, M., Rattanasone, N. X., Tek, S., Khetrapal, N., Fein, D., et al. (2016). You're telling me! The prevalence and predictors of pronoun reversals in children with autism spectrum disorders and typical development. *Res. Autism Spectr. Disord.* 27, 11–20. doi: 10.1016/j.rasd.2016.03.008

Ohta, M. (1987). Cognitive disorders of infantile autism: a study employing the WISC, spatial relationship conceptualization, and gesture imitations. *J. Autism Dev. Disord.* 17, 45–62. doi: 10.1007/BF01487259

Oshima-Takane, Y. (1992). Analysis of pronominal errors: a case-study. *J. Child Lang.* 19, 111–131. doi: 10.1017/S0305000900013659

Overweg, J., Hartman, C. A., and Hendriks, P. (2018). Children with autism spectrum disorder show pronoun reversals in interpretation. *J. Abnorm. Psychol.* 127, 228–238. doi: 10.1037/abn0000338

Padden, C. (1991). "The acquisition of fingerspelling by deaf children," in *Theoretical issues in sign language research*. eds. P. Siple and S. Fischer, vol. *2*. Psychology (Chicago, IL: University of Chicago Press), 191, 191–210, 210.

Petitto, L. A. (1987). On the autonomy of language and gesture: evidence from the acquisition of personal pronouns in American sign language. *Cognition* 27, 1–52. doi: 10.1016/0010-0277(87)90034-5

Pizzuto, E. (1990). "The early development of deixis in American sign language: what is the point?" in *From gesture to language in hearing and deaf children*. eds. V. Volterra and C. Erting (Washington, DC: Gallaudet University Press), 142–162.

Ricks, D. M., and Wing, L. (1975). Language, communication, and the use of symbols in normal and autistic children. *J. Autism Dev. Disord.* 5, 191–221. doi: 10.1007/BF01538152

Rogers, S. J., and Pennington, B. F. (1991). A theoretical approach to the deficits in infantile autism. *Dev. Psychopathol.* 3, 137–162. doi: 10.1017/S0954579400000043

Rutter, M., Bailey, A., and Lord, C. (2003). *Social Communication Questionnaire*. Western Psychological Services, Los Angeles.

Shield, A., Igel, M., Randall, K., and Meier, R. P. (2020). The source of palm orientation errors in the signing of children with ASD: imitative, motoric, or both? *Brain Sci.* 10:268. doi: 10.3390/brainsci10050268

Shield, A., Knapke, K., Henry, M., Srinivasan, S., and Bhat, A. (2017). Impaired praxis in gesture imitation by deaf children with autism spectrum disorder. *Autism Dev. Lang. Impair.* 2, 1–14.

Shield, A., and Meier, R. P. (2012). Palm reversal errors in native-signing children with autism. *J. Commun. Disord.* 45, 439–454. doi: 10.1016/j.jcomdis.2012.08.004

Shield, A., and Meier, R. P. (2018). Learning an embodied visual language: four imitation strategies available to sign learners. *Front. Psychol.* 9:811. doi: 10.3389/fpsyg.2018.00811

Shield, A., Meier, R. P., and Tager-Flusberg, H. (2015). The use of sign language pronouns by native-signing children with autism. *J. Autism Dev. Disord.* 45, 2128–2145. doi: 10.1007/s10803-015-2377-x

Shield, A., Pyers, J., Martin, A., and Tager-Flusberg, H. (2016). Relations between language and cognition in native-signing children with autism spectrum disorder. *Autism Res.* 9, 1304–1315. doi: 10.1002/aur.1621

Tacchetti, M. (2017). *User's guide for ELAN linguistic annotator*. The Language Archive, MPI for Psycholinguistics, Nijmegen, The Netherlands.

Tager-Flusberg, H. (1994). "Dissociations in form and function in the acquisition of language by autistic children," in *Constraints on language acquisition: Studies of* *atypical children*. ed. H. Tager-Flusberg (Hillsdale, NJ: Lawrence Erlbaum Associates), 175–194.

Tager-Flusberg, H. (1996). Brief report: current theory and research on language and communication in autism. *J. Autism Dev. Disord.* 26, 169–172. doi: 10.1007/BF02172006

Tager-Flusberg, H. (2006). Defining language phenotypes in autism. *Clin. Neurosci. Res.* 6, 219–224. doi: 10.1016/j.cnr.2006.06.007

Tek, S., Mesite, L., Fein, D., and Naigles, L. (2014). Longitudinal analyses of expressive language development reveal two distinct language profiles among young children with autism spectrum disorders. *J. Autism Dev. Disord.* 44, 75–89. doi: 10.1007/s10803-013-1853-4

Wimmer, H., and Perner, J. (1983). Beliefs about beliefs: representation and constraining function of wrong beliefs in young children's understanding of deception. *Cognition* 13, 103–128. doi: 10.1016/0010-0277(83)90004-5

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# Somatosensory processing in deaf and deafblind individuals: How does the brain adapt as a function of sensory and linguistic experience? A critical review

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How do deaf and deafblind individuals process touch? This question offers a unique model to understand the prospects and constraints of neural plasticity. Our brain constantly receives and processes signals from the environment and combines them into the most reliable information content. The nervous system adapts its functional and structural organization according to the input, and perceptual processing develops as a function of individual experience. However, there are still many unresolved questions regarding the deciding factors for these changes in deaf and deafblind individuals, and so far, findings are not consistent. To date, most studies have not taken the sensory and linguistic experiences of the included participants into account. As a result, the impact of sensory deprivation vs. language experience on somatosensory processing remains inconclusive. Even less is known about the impact of deafblindness on brain development. The resulting neural adaptations could be even more substantial, but no clear patterns have yet been identified. How do deafblind individuals process sensory input? Studies on deafblindness have mostly focused on single cases or groups of late-blind individuals. Importantly, the language backgrounds of deafblind communities are highly variable and include the usage of tactile languages. So far, this kind of linguistic experience and its consequences have not been considered in studies on basic perceptual functions. Here, we will provide a critical review of the literature, aiming at identifying determinants for neuroplasticity and gaps in our current knowledge of somatosensory processing in deaf and deafblind individuals.

KEYWORDS

**Somatosensory processing, deafness, deafblindness, signed languages, tactile languages, linguistics, neuroplasticity**

## Introduction

Our brain constantly receives and processes signals from the environment and combines them into a multisensory percept—resulting in the most reliable information content. The perceptual system is not fully present at birth but develops as a function of individual experience, which thus shapes brain functions (Bavelier and Neville, 2002; Knudsen, 2004). The different senses are specialized for different stimulus features. While vision offers the most precise information for spatial perception, audition is the most dependable channel for temporal information, and touch for texture perception (Welch and Warren, 1980).

In the case of sensory deprivation, the nervous system changes as a function of the altered input. A total sensory deprivation from birth—such as congenital deafness or deafblindness—can be a unique model for expanding the knowledge about the prospects and limitations of neuroplasticity (for reviews see Merabet and Pascual-Leone, 2010; Pavani and Röder, 2012). However, to date, the network and interplay of the different sensory modalities have not been fully understood. How does the brain respond to unisensory (deafness) or bisensory (deafblindness) deprivation? What is the impact of the age of onset? To which degree might language experience and age of language exposure impact basic perceptual functions, and does language modality matter? All these questions can be linked to the broader context of neuroplasticity. So far, the answers have remained inconclusive.

Neuroplasticity is defined as the ability of the brain to adapt its organization to the specific sensory experiences of an individual (Sheedlo and Turner, 1992). Changes can be observed on the structural level, such as alterations of axonal, dendritic, and synaptic morphologies, or a functional level, that is, modulations in the weights of synaptic connections (Knudsen, 2004). Although the brain remains plastic throughout the lifespan, adult plasticity is more limited in both qualitative and quantitative aspects as compared to developmental plasticity (Knudsen, 2004). Neuroplasticity after sensory deprivation can be classified into two types, corresponding to the brain area in which the change occurs (for reviews see Pavani and Röder, 2012; Heimler et al., 2014). *Intramodal plasticity* refers to changes in a brain area that is typically associated with the processing of a spared modality, such as higher cortical volume in visual areas of deaf participants in comparison to hearing individuals (Bottari et al., 2011; Allen et al., 2013; Scott et al., 2014). For example, Allen et al. (2013) found a larger volume of gray matter in primary visual cortex of congenitally deaf individuals than in both hearing signers and non-signers. This review will focus on studies on *crossmodal plasticity*, which concerns changes in areas that are typically associated with a modality that is not received and processed. Examples are higher activity in auditory areas in deaf compared to hearing individuals during visual stimulation (Finney et al., 2001; Fine et al., 2005; Benetti et al., 2021) and tactile stimulation (Karns et al., 2012; Zimmermann et al., 2021), or activity in visual areas of blind individuals who are listening to speech (Bedny et al., 2011). Benetti et al. (2021) presented patterns of moving dots and observed significantly stronger activation in typical auditory areas in early deaf participants compared to hearing signers and non-signers. Moreover, activation of auditory areas in early deaf signers has been observed during sign language processing (Nishimura et al., 1999; Petitto et al., 2000). These findings point to the relevance of visual motion and visual language input for studies on neuroplasticity in deaf individuals. Importantly, crossmodal reorganization does not follow a random pattern but seems to be functionally selective. As a result, brain regions sustain their typical function in deprived individuals but process it in a spared sense instead (Dormal and Collignon, 2011). Indications of functional selectivity have been shown in studies on visual processing in deaf humans (e.g., Benetti et al., 2017, 2021; Bola et al., 2017) and non-human animals (e.g., Lomber et al., 2010).

Neuroplastic changes have been observed after a congenital, early, and even late onset of sensory deprivation (for deafness, see, e.g., Allman et al., 2009; Sandmann et al., 2012). However, compared to developmental plasticity, the impact of adult plasticity is significantly reduced (for reviews see Bavelier and Neville, 2002; Heimler et al., 2014). Behavioral differences between sensory-deprived individuals and control groups have been associated with changes on the neural level (Gilbert et al., 2001). An impactful example comes from the animal model. Congenitally deaf cats outperformed hearing cats in visual localization of peripherally presented stimuli and visual motion detection. These superior skills could be linked to changes in the posterior auditory field (PAF) in deaf cats, which is associated with auditory localization in hearing cats (Lomber et al., 2010). Changes in auditory areas of deaf cats were also identified at the level of neural layers, which were thinner than in hearing cats (Berger et al., 2017). To understand the underlying modulations, it is crucial to distinguish between different perceptual functions, such as spatial and temporal processing (Cardin et al., 2020). For example, congenitally blind individuals have been shown to outperform sighted controls in tactile temporal order judgment tasks but have displayed deficits in spatial abilities (e.g., Röder et al., 2004). In general, sensory deprivation has been associated with three possible behavioral outcomes: (1) *Hyper-compensation,* that is, better performance, (2) *crossmodal compensation*, resulting in no behavioral differences, and (3) lower performance, supporting the *perceptual deficiency hypothesis* (for a review see Pavani and Röder, 2012).

Furthermore, when examining how individual experiences impact neural organization, considering the role of timing during ontogeny is crucial. The development of perceptual, cognitive, and socio-emotional skills is characterized by specific and limited time windows. For typical progress, certain input must be received within these sensitive and critical periods (Knudsen, 2004). Critical periods have been identified for the development of the sensory systems, such as the auditory system (Sharma et al., 2002; Kral, 2013). Studies in early deaf children who received a cochlear implant (CI) have suggested that for the development of the auditory system, the first 7 years of the lifespan are critical (Weber-Fox and Neville, 1996; Putzar et al., 2007). Other studies have defined an even earlier time window, recommending implantation before the age of 3.5–4.0 years, but not later than 7 years of age (Sharma et al., 2002). Critical periods also exist for higher cognitive functions, such as specific language functions (for a review see Kuhl, 2011). In the case of severely delayed exposure to a first language, some language functions, such as complex syntactic structure, might be irreversibly lost (e.g., Mayberry et al., 2002). Notably, other linguistic features—for example, semantic processing—seem to be less susceptible to critical periods, and the effects of age of acquisition are very different for first and second language acquisition (Curtiss, 1977; Mayberry and Kluender, 2017).

Thus, due to developmental neuroplasticity and critical periods in ontogeny, age of deprivation onset can be considered a crucial variable in studies on deafness and deafblindness (Knudsen, 2004; Kral, 2013). Furthermore, individual language experiences should be examined. Here, a critical determinant might be the age of exposure to a first language. For some participants in studies on somatosensory processing in deaf and deafblind individuals, this will be a signed language. Signed languages are natural, full, and complex languages, which allow a typical development of language areas in the brain (Mayberry and Kluender, 2017). If acquired from birth, signed and spoken languages mostly recruit the same neural network (Neville et al., 1998; Emmorey et al., 2002; MacSweeney et al., 2002; Mayberry et al., 2011; for a review see Campbell et al., 2008). However, in addition to modality-independent language areas, some specific areas are more active or recruited only for signed languages compared to spoken languages (Emmorey et al., 2007, 2014). This might have an impact on, for example, the lateralization of the neural response to non-linguistic stimuli (Bosworth and Dobkins, 1999; Ferjan Ramirez et al., 2014; Bottari et al., 2020). On the other end of the language acquisition continuum, there are deaf and deafblind participants who have never fully acquired a language. Language deprivation due to delayed exposure to a first language changes the organization of language areas in the brain and may have an impact on other, more basic perceptual functions (MacSweeney et al., 2008; Mayberry et al., 2011). However, this perspective has not always been sufficiently taken into account, rendering some of the outcomes of the existing studies unclear.

## Subsections relevant for the subject

### Deaf participants

For deaf individuals, most of the existing work has focused on the visual system (Neville and Lawson, 1987a,b; Finney et al., 2001, 2003; Bosworth and Dobkins, 2002; Fine et al., 2005; Bottari et al., 2014; Almeida et al., 2015; Dewey and Hartley, 2015). Contrary to the visual modality, the development of the somatosensory system and processing of tactile stimuli in deaf individuals have thus far received significantly less attention (Levänen et al., 1998; Levänen and Hamdorf, 2001; Bolognini et al., 2012; Karns et al., 2012; Hauthal et al. 2015; for the animal model, see Meredith and Lomber, 2011). It has been a matter of debate if auditory deprivation results in perceptual deficits or advantages concerning specific stimulus features (for a review see Pavani and Röder, 2012). Importantly, deaf individuals do not display altered processing skills *per se*, but rather for specific tasks (for reviews see Bavelier et al., 2006; Pavani and Bottari, 2012). Activation of auditory areas in deaf individuals has been mostly, but not exclusively, reported for visual motion stimuli (Bavelier et al., 2001; Finney et al., 2001, 2003; Fine et al., 2005; Dewey and Hartley, 2015). Based on the applied methodology, the studies will be separated into behavioral and neuroimaging studies.

#### Behavioral performance

Behaviorally, the results from different studies do not show a clear pattern. Behavioral enhancements as a result of auditory deprivation, that is, a *hyper-compensation* have been observed in deaf adults in, for example, the detection of tactile frequency changes (Levänen and Hamdorf, 2001) or haptic spatial orientation abilities (Van Dijk et al., 2013a). Earlier studies have also found better performance in deaf compared to hearing children in tactile localization tasks (e.g., Chakravarty, 1968). Levänen and Hamdorf (2001) investigated tactile frequency change detection and frequency discrimination abilities in congenitally deaf participants ($n = 6$; age range: 18–23 years) and a hearing control group ($n = 6$; age range: 22–27 years). All deaf participants were reported to be fluent users of FinSL (Finnish Sign Language), but no further information on their language backgrounds (such as the age of acquisition) is provided. The stimuli consisted of vibrations that were presented to the palm and fingers by a vibrating plastic tube. In the frequency change detection task, participants had to detect deviants with a frequency of 180 Hz, as opposed to 250 Hz standards. In the frequency discrimination task, participants had to decide whether the difference between a changing vibration ranging between 160–250 Hz and a 200 Hz reference stimulus was increasing or decreasing. The difference was decreased as a function of individual response accuracy. The results showed an enhanced tactile sensitivity, that is, better detection rates of the unpredictable tactile frequency changes for congenitally deaf individuals compared to hearing controls. In the task on tactile frequency discrimination, Levänen and Hamdorf (2001) did not observe differences between groups—indicating a *crossmodal compensation* in the deaf group. This is in accordance with results from studies on tactile spatial length discrimination (Bolognini et al. 2012).

Contrary to the findings by Levänen and Hamdorf (2001) on tactile frequency detection, Moallem et al. (2010) did not observe differences between deaf and hearing individuals in mean detection thresholds of tactile stimulation (frequency range: 2–300 Hz) to different fingers (thumb, index finger, middle finger). Importantly, while the included deaf participants ($n = 9$; age range: 18–56 years) were congenitally deaf, their language experiences varied highly. Early languages were reported as "ASL, signed exact English (SEE), Pidgin signed English (PSE), spoken English, cued English, and total communication" (Moallem et al., 2010). Reported language usage of the deaf group is divided into "early" and "current"; no specific ages of acquisition were provided. The control group consisted of hearing participants ($n = 5$; age range: 23–58 years) who had acquired spoken language as a first language. Therefore, in addition to the comparably small sample, the two groups displayed very different language acquisition backgrounds.

The results by Moallem et al. (2010) are in line with those from a study by Heimler and Pavani (2014) on simple tactile detection in early and congenitally deaf participants ($n = 8$; mean age = 34.2 years, $SD = 5.5$) and a hearing control group ($n = 12$; mean age = 28.6 years, $SD = 2.7$). The language background of the deaf participants varied. Two had never acquired a signed language, whereas the other six were late learners of Italian Sign Language (LIS) (age of acquisition range: 7–21 years). Tactile stimulators were attached to the fingertips, the forearms, and the neck (the latter location was investigated in the deaf group only). The groups did not differ in response time, and there was no difference in behavioral performance for the deaf group as a function of tactile stimulation location. Yet another different outcome, that is, lower performance in tactile detection in congenitally deaf (age range: 14–20 years; language backgrounds not reported) compared to hearing participants was reported by Frenzel et al. (2012).

Another example of better tactile performance in deaf compared to hearing individuals was reported by Van Dijk et al. (2013a). In this study, a haptic spatial orientation task was presented to congenitally deaf signers ($n = 15$; mean age = 41.4 years, age range: 19–66 years), hearing sign language interpreters ($n = 16$; mean age = 38.4 years, age range: 26–51 years), and hearing controls ($n = 16$; mean age = 44.8 years, age range: 26–57 years). All deaf participants had acquired a signed language (Sign Language of the Netherlands, NGT) as their first language; all hearing signers had a bachelor's degree in interpreting, three had deaf parents and grew up with NGT from birth. The signing skills of the other hearing interpreters were described as "near native" (no additional language assessment tasks were performed). The participants were blindfolded and asked to set a test bar parallel to a reference bar with an orientation of 0°, 30°, 60°, 90°, 120°, or 150°. Both bars were placed on a table in front of the participants. They first touched the reference bar with their right hand and, after a delay of 2 or 10 s, respectively, adjusted the test bar accordingly with their left hand. The results revealed better haptic spatial orientation processing skills in the deaf group than in hearing signers and non-signers.

Notably, in a second study from the same authors including a tactile spatial configuration task, sensory experience was not the critical determinant for altered behavioral performance (Van Dijk et al., 2013b). Here, enhanced somatosensory processing was observed as a result of the acquisition and usage of NGT instead. Based on the participants' background information, it can be assumed that the task was presented to almost the same sample as in Van Dijk et al. (2013a): early deaf individuals ($n = 15$; mean age = 41.4 years, age range: 16–66 years), hearing interpreters ($n = 16$; mean age = 38.4 years, age range: 26–51 years), and hearing controls ($n = 16$; mean age = 44.8 years, age range: 26–57 years). The experiment consisted of three parts, divided into five trials. In the first part (trials 1–3), the blindfolded participants had to match 10 haptically presented shapes to cut-outs on a wooden board, which they had not seen before. In the second part (trial 4), the shapes had to be placed in their previous positions on a board without cut-outs. In the third part (trial 5), the wooden board with cut-outs was rotated while the shapes had to be placed again. Reaction time was measured for the first and the third part of the study. Results revealed that the deaf and hearing signers were significantly faster and outperformed the hearing non-signers in trials 1–3 and 5. This indicates that it is not only the sensory deprivation but also language experience which can shape the processing of touch in individuals. No differences between groups were observed in the second part of the study, (trial 4).

Some studies on somatosensory processing in deaf individuals have supported the *perceptual deficiency theory*, which states that the loss of one sensory modality will negatively impact the spared modalities (for a review see Pavani and Röder, 2012). This perspective has been supported by, for example, studies on temporal discrimination of tactile stimuli, in which deaf individuals performed significantly worse than hearing controls (e.g., Heming and Brown, 2005; Bolognini et al., 2012; Papagno et al., 2016). In a study on temporal detection skills, Heming and Brown (2005) presented tactile and visual stimulation to congenitally and early deaf individuals ($n = 20$; mean age = 22.44 years, age range: 18–31 years) and a matched hearing control group ($n = 20$; mean age = 22.70 years, age range: 18–32 years). All deaf participants reported American Sign Language (ASL) as their first language—however, no further information on language acquisition and usage was provided, and it is possible that some did experience delayed language acquisition. In the tactile task, participants had to detect if two mechanical tactile stimulations presented to the index and the middle finger of the left, right or both hands occurred simultaneously or not (in fact, the stimuli were never presented fully simultaneously). The results revealed significantly higher temporal detection thresholds for the deaf group than the hearing group (deaf group: mean = 84.18 ms, $StD = 25.34$ ms; hearing group: mean = 21.59 ms, $StD = 14.99$ ms).

Bolognini et al. (2012) also addressed the question of how tactile abilities will be impacted by auditory deprivation. To this end, they presented tactile stimuli in two different tasks (temporal and spatial) to groups of congenitally deaf individuals and hearing controls. In the temporal task, nine deaf participants (mean age = 41 years, age range: 25–52 years) and nine hearing controls (mean age = 38 years, age range: 27–60 years) were included. Seven of the deaf participants had acquired LIS before the age of 3 years because they had one or two deaf parents or attended an institution in which LIS was used. The other two deaf participants had not acquired a signed language. No further details on individual language backgrounds were provided. For the spatial task, seven deaf and seven hearing individuals participated. The mean age was 44 years for the deaf group (age range: 25–53 years) and 32 years for the hearing controls (age range: 24–49 years). Five of the deaf participants were early signers (<3 years), and the other two were non-signers. Vibrotactile stimuli were attached to the index fingers of both hands. In the temporal task, participants discriminated stimuli with a duration of 15 ms or 25 ms, respectively (with interrupting pulses after each 5 ms). The stimulation was presented to the fingertips of the index fingers. In the spatial task, the participants discriminated the spatial length of the stimulation, which was presented to either two or three points on the index fingers. Behavioral results on perceptual sensitivity revealed that the hearing controls significantly outperformed the deaf group in the temporal task, whereas no differences between groups were observed in the spatial task.

In a different kind of temporal task, Sharp et al. (2018) found an altered performance in congenitally deaf individuals ($n = 13$; mean age = 38.4 years, age range: 29–57 years) compared to hearing controls ($n = 13$; mean age = 33.4 years, age range: 20–59 years) in a temporal order judgement task (TOJ). Tactile stimulation was delivered through a small foam cube that was held between the thumb and index fingers of both hands. The stimulus onset asynchrony (SOA) varied and was ±400, ±200, ±100, or ±50 ms. Participants had to decide on which side the stimulation was presented first (left or right; negative SOA values for trials in which the stimulation was presented on the left hand first). The experiment included conditions with uncrossed and crossed arms. Compared to the hearing controls, the deaf group showed significantly higher error rates in the blocks with crossed arms. The authors concluded that the deaf individuals were less successful in managing the "conflict between visual and somatosensory body-related information through a change in posture" (Sharp et al., 2018). Notably, though, 12 of the deaf 13 deaf participants used spoken language, whereas only one of the participants primarily communicated in a signed language. No information is given about the deaf participants' language acquisition history and, thus, it is not possible to disentangle the impact of deafness vs. language experience.

In a study including a visuo-tactile TOJ task with a crossed-arms condition, Scurry et al. (2020a) tested early deaf ($n = 12$; mean age: 41.73 years) and matched hearing participants while they recorded the EEG. Here, the results did not reveal accuracy differences, that is, temporal order discrimination and perceived synchrony of the visuo-tactile stimulation. Importantly, while the authors provide detailed information about the etiologies of the participants, this is not the case for their language backgrounds. The observation of crossmodal compensation is in line with other studies that have reported similar behavioral outcomes for deaf and hearing groups in temporal processing (Bross and Sauerwein, 1980; Poizner and Tallal, 1987; Nava et al., 2008; Moallem et al., 2010). For example, Moallem et al. (2010) did not find group differences in tactile temporal processing skills of congenitally deaf individuals and hearing controls. In their task, stimuli of 50 Hz at the thumb and 250 Hz were delivered at the index finger and either asked which stimulus was preceding the other one or which was presented later, respectively. There was a high amount of individual variability in behavioral outcomes in both groups, especially the deaf group.

While somatosensory processing has not yet been extensively investigated in deaf individuals, even less is known about the interaction of the spared senses as a consequence of auditory deprivation. In the first study on visuo-tactile processing in congenitally deaf individuals ($n = 13$; all participants reported having a family history of congenital deafness and acquired ASL in childhood), Karns et al. (2012) observed evidence for altered multisensory processing compared to hearing controls as well as reorganization of auditory brain regions. In an fMRI study, they presented a touch–induced flash illusion—a single flash is perceived as two flashes if two tactile stimuli are presented at the same time, analogously to the sound-induced double flash illusion (Shams et al., 2000; Violentyev et al., 2005). Only the deaf individuals were susceptible to the illusion for reduced auditory-tactile interactions in congenitally blind individuals compared to sighted controls, see (Hötting et al., 2004; Hötting and Röder, 2004). This was interpreted as a stronger multisensory interplay between vision and touch as a result of deafness (Karns et al., 2012).

Hauthal et al. (2015) presented a speeded detection task with visual, tactile, and crossmodal stimulation while they recorded the EEG. The findings revealed a reduced redundancy gain in response times (RTs) for crossmodal versus unimodal stimulation in congenitally and early deaf individuals ($n = 10$; mean age = 43, $SD = 7$ years, age range: 36–57 years) compared to hearing controls ($n = 10$; mean age = 43, $SD = 9$ years). The deaf participants were all signers of German Sign Language (DGS), however, the age of acquisition varied and only one participant had acquired DGS from birth.

In a recent EEG study investigating visuo-tactile motion processing, Villwock et al. (2022) observed a higher false alarm rate for incongruent motion stimuli in congenitally deaf native signers of DGS ($n = 21$; mean age = 26.14 years, age range: 19–48 years) compared to matched hearing non-signers. The tactile motion was presented to the index fingers of both hands; the visual motion was presented *via* adjacently located LED lights. Participants were asked to detect deviants with an interrupted movement which were going in a target direction. Importantly, for the deviant stimuli, only one of the modalities (visual or tactile) was interrupted. The false alarm rate did not differ between groups in the congruent condition, indicating different stimulus selection strategies in congenitally deaf signers compared to hearing non-signers.

## Neuroscientific results

Only a few neuroscientific studies have investigated somatosensory processing in deaf individuals, and some reported responsiveness of auditory areas to tactile stimulation that was not present in hearing controls (Levänen et al., 1998; Auer et al., 2007). Evidence of crossmodal plasticity—that is, enhanced activation of auditory areas following tactile stimulation in deaf individuals compared to hearing controls—has been found in studies applying magnetoencephalography (MEG) (e.g., Levänen et al., 1998) as well as functional magnetic resonance imaging (fMRI) (e.g., Auer et al., 2007; Karns et al., 2012). Furthermore, single-unit recording studies have reported responsiveness of neurons in auditory cortices of deaf non-human animals following both somatosensory and visual stimulation (e.g., Allman et al., 2009; Meredith and Allman, 2009, 2012; Meredith and Lomber, 2011; Land et al., 2016).

In a single-case magnetoencephalogram (MEG) study including tactile stimulation to the fingers and the palm of the left hand, Levänen et al. (1998) observed responses in primary auditory areas of a senior deaf participant (age = 77 years), but not in a group of hearing control participants ($n = 6$; age range: 26–37 years). Moreover, the MEG analysis revealed specific responses in auditory areas to 180 Hz vs. 250 Hz, respectively. The congenitally deaf participant was a signer of Finnish Sign Language (FinSL) and came from a family with five deaf siblings. Thus, the results might indicate changes due to neuroplasticity after auditory deprivation—and/or as a result of FinSL acquisition.

Indication of crossmodal reorganization was also found in an fMRI study by Auer et al. (2007). The fMRI has a better spatial resolution than MEG. Here, the sample was more balanced than in Levänen et al. (1998) and consisted of six deaf participants (mean age = 23 years, age range: 19–26 years) and six hearing controls (mean age = 24 years, age range: 19–31 years). Two of the deaf participants were congenitally deaf; the etiology of the other participants was unknown. All reported to have used hearing aids in the past; information on language backgrounds is not provided. The vibro-tactile stimulation was either derived from speech or at a fixed frequency of 125 Hz sine waves and presented at the right thumb. The activation of auditory areas was significantly stronger and more widely distributed in the deaf individuals than in hearing controls for both types of stimulation (Auer et al., 2007).

In their study on temporal and spatial tactile perception in congenitally deaf individuals and a hearing control group, Bolognini et al. (2012) examined the effect of deafness on the processing of touch. They applied transcranial magnetic stimulation (TMS) to monitor the timing of involvement of the primary somatosensory area (S1) and Superior Temporal Gyrus (STG) as a function of the somatosensory processing. Behaviorally, the hearing group outperformed the deaf group in the temporal task, but no such group differences were observed for the spatial task. The TMS results showed that in addition to primary somatosensory areas (S1), both tasks involved activation in the auditory association cortex at a time window of 60–120 ms in deaf individuals. For hearing controls, a similar pattern was observed in SI, however, the STG displayed involvement at a later latency of 180 ms, and only for the temporal task. For the hearing group, this area was involved at a later latency (180 ms) and for the task of temporal discrimination only (for hearing participants see also Bolognini et al., 2010). Moreover, analyses revealed a correlation between temporal discrimination task performance and the effect of disruption by STG-TMS at 180 ms: The better the behavioral performance, the larger the disruption induced by the STG-TMS at that time point. In a recent fMRI study, Zimmermann et al. (2021) also found different results for temporal vs. spatial somatosensory processing in a group of deaf and hard-of-hearing participants ($n = 21$). All participants were signers of Polish Sign Language (PJM), and their age of acquisition ranged from birth to primary school entry. While both stimulus types resulted in the recruitment of auditory cortex, this was task-specific for the temporal task only. On the contrary, spatial stimulation evoked activation in auditory areas regardless of the experimental task. Moreover, the activation was more widely spread for spatial compared to temporal processing.

Contrary to these results, Hickok et al. (1997) did not find indicators of crossmodal plasticity in an MEG study with one congenitally deaf participant (28 years old), who had acquired ASL from birth. Although the observed activity patterns were compared with those of hearing control participants, a control group is not specified. The stimulation included visual and tactile stimulators, and a motor task (self-paced finger-tapping) was conducted. No behavioral task was included. Tactile stimulation consisted of mechanical taps (17–20 psi, duration = approx. 30 ms) that were presented at digit segments, the lip, and the tongue. The results did not reveal activation in auditory areas, responses were observed in visual, somatosensory, and motor areas.

While to date, somatosensory processing has not been thoroughly investigated in deaf individuals, even less is known about the neural patterns regarding the interplay of vision and touch in deaf individuals (Karns et al., 2012; Villwock et al., 2022). In the first human study on multisensory processing in congenitally deaf individuals, Karns et al. (2012) used fMRI to examine visual, tactile, and visuo-tactile stimulation processing. The stimuli were static, tactile stimulation consisting of air puffs presented to the face. The fMRI results showed evidence for enhanced multisensory processing associated with a reorganization of auditory brain regions. Deaf individuals showed significantly stronger activation of primary auditory cortices (Heschl's gyrus) than hearing controls for all stimulus types. Responses in Heschl's gyrus were more enhanced for crossmodal and tactile stimulation than for visual stimulations. The response in superior temporal sulcus (STS) was comparable for the visual modality. Moreover, it was only the deaf group that was susceptible to a touch-induced double-flash illusion, and the strength of the illusion was positively correlated to the associated signal changes in auditory cortices. The results point to altered multisensory processing and crossmodal reorganization after congenital deafness (Karns et al., 2012).

In an fMRI study on tactile motion processing, Scurry et al. (2020b) tested seven early deaf participants (age range: 31–55 years) and matched hearing controls (age range: 28–54 years). Language backgrounds were not reported. Tactile stimuli were presented to the right index finger and included four different directions of motion: Up, down, left, and right (each presented for 2 s). Participants performed a behavioral task to ensure their attention to the stimuli, however, behavioral results were not reported. The results of a population receptive field analysis revealed a comparable neural response of the groups to tactile motion in primary and secondary somatosensory cortices. However, compared to hearing controls, the deaf group displayed a lower proportion of directionally tuned voxels in primary somatosensory cortex. Furthermore, they showed larger responses to tactile motion in the right posterior superior temporal sulcus (pSTS), pointing to crossmodal plasticity as a result of the early auditory deprivation. This is in accordance with findings from González-Garrido et al. (2017), who presented an oddball task with vibrotactile stimuli to early deaf participants ($n = 14$; mean age = 21.96 years, SD = 6.63 years) and matched hearing controls ($n = 14$; mean age = 21.93 years, SD = 5.02 years). Except for one native signer, all deaf participants acquired Mexican Sign Language (LSM) after the age of 7 years. To investigate how the somatosensory system might be a substitute for auditory input and support the perception of speech, training with sound wave stimuli (five 1-h long sessions) was conducted. The training stimuli were targeting pure tone frequency and duration discrimination, but also complex natural sounds. Stimulation was presented to the right index finger. The oddball task with 700 and 900 Hz pure tones (80% standards, 20% deviants) was performed pre-and post-training. ERP analyses revealed differences in the topography of the electrophysiological response between groups. In a time window comprising the P3 wave, a right lateralized response was observed for the deaf, but not the hearing group.

In an EEG study investigating visual, tactile, and crossmodal static stimulation in a simple detection redundant target task, Hauthal et al. (2015) observed a shorter latency of the N200 for visuo-tactile in comparison to unimodal tactile conditions in hearing participants compared to a group of congenitally deaf native signers. This might suggest an altered and delayed multisensory processing as a consequence of congenital deafness (Hauthal et al., 2015). However, the deaf group also displayed significantly shorter N200 latencies than the hearing group in the unimodal tactile condition—presumably leading to a larger difference between visuo-tactile and tactile latencies in the hearing group. Hauthal et al. (2015) observed a delayed latency of the N200 in deaf individuals compared to hearing controls for visuo-tactile in comparison to unimodal tactile conditions, possibly suggesting altered multisensory processing as a result of auditory deprivation.

In another recent EEG study, Scurry et al. (2020a) examined temporal processing skills in early deaf participants and hearing controls. They employed a TOJ task with visual and tactile stimuli. There were no behavioral differences between groups. However, the ERP results displayed larger amplitudes of both the visual P100 (for all SOA levels) and the tactile N140 (for the shortest asynchronous presentation at ±30 ms as well as synchronous stimuli) in deaf compared to hearing participants. Furthermore, the deaf group showed a longer latency in the somatosensory P200 than the hearing control group.

Villwock et al. (2022) presented congruent and incongruent visuo-tactile motion stimuli to congenitally deaf first language and first modality (L1M1) signers, and hearing controls. The ERP results showed a delayed congruency of motion effect in the deaf group compared to hearing controls (200–280 ms vs. 348–448 ms after stimulus onset, respectively), and thus, do not point to enhanced motion direction-specific interactions between the visual and tactile system. The lateralization of the congruency effect was opposed for the groups—the deaf group showed a left lateralized response, whereas the effect was right lateralized in the controls. Moreover, ERPs between 140 and 164 ms were more anteriorly distributed in the deaf than in the hearing group, possibly indicating activation in auditory areas as a consequence of crossmodal plasticity.

### Summary: deaf participants

To conclude, there are comparably few studies on the impact of deafness on the somatosensory system, and both the processing of touch and the crossmodal interplay of the spared modalities are not well understood. So far, studies have revealed different results in performance and neural responses to stimulation, including the lateralization of activation. These inconsistencies might be partly based on the specific tasks in the studies. Furthermore, they might be due to highly heterogeneous samples of deaf participants both between and within studies. So far, deaf participants with very different backgrounds are often assigned to the same group. This includes congenitally vs. early and late deaf individuals, and highly different backgrounds regarding language acquisition. In some cases, in which the deaf samples were rather homogeneous regarding their sensory experiences, language experience was not taken into account (e.g., Heming and Brown, 2005). The studies which considered both factors (e.g., Villwock et al., 2022), have mostly focused on congenitally deaf L1M1 signers and compared them to non-signing hearing control groups. As a result, the impact of sensory deprivation vs. the usage of a signed language cannot be fully distinguished, impeding an unambiguous interpretation of the results.

## Deafblind participants

Including the group of deafblind individuals allows crucial insights into the consequences of audio-visual deprivation on the perception of touch. Importantly, individual etiologies for deafblindness are highly heterogeneous (Dammeyer, 2013), a factor that must be taken into account when considering the number and outcome of existing studies. To date, there is little insight into how somatosensory processing in deafblind individuals might be altered as a function of the specific sensory deprivation and individual language experience. Compared to unisensory information, a combination of different sensory modalities usually results in enhanced performance, e.g., for response times (Meredith and Stein, 1986; Stein et al., 2010). This may be due to the supramodal characteristics of an event—e.g., space and time—which can be simultaneously coded by the different sensory systems. Unimodal stimulation is seen to be relatively weak compared to a multimodal percept (Stein et al., 2010), and multisensory neurons have been found in different brain regions in individuals (for reviews see Stein and Stanford, 2008; Murray et al., 2016). However, so far, it remains inconclusive how the brain organizes itself as a function of a bisensory deprivation such as deafblindness. Furthermore, it remains unknown if and how the sensory processing of congenitally deafblind individuals might differ from congenitally deaf individuals, who became blind later in life.

The sensory experiences of deafblind participants differ due to their etiology. There are numerous possible reasons for deafblindness in humans, resulting in high variability of individual experience. Etiologies can include pre-, peri-and postnatal causes. This includes, *inter alia*, congenitally deafblind individuals and those who were born deaf, but experienced a later onset of blindness (e.g., due to *Usher syndrome;* Vernon, 1969). The exact number of deafblind individuals in a community is often unknown. For example, based on information from community members, the German deafblind community might consist of approximately 10,000 members, most of them seniors. A previous study in Denmark provided an estimate for a prevalence of 1: 29,000 for congenital deafblindness in the Danish population. Late deafblindness has a significantly higher frequency in seniors compared to children and younger adults. In general, there is a larger number of older deafblind people than deafblind children and young adults (Dammeyer, 2010, 2013).

While linguistic experiences in the Deaf Community display a considerable degree of variance, the situation is even more complex for deafblind individuals, and individual language backgrounds are highly diverse (Mesch, 2001; Willoughby et al., 2014; Edwards and Brentari, 2021). This is partly due to the heterogenous nature of deafblindness, such as the age of onset of blindness. Exposure to language in this sample can also depend on coexisting intellectual conditions. Furthermore, expressive and receptive communication channels might differ, for example, based on individual motor skills. Language acquisition and usage can include, *inter alia*, early or delayed acquisition of a signed language, a signed communication system, a tactile sign language, or tactile systems such as *Lormen* (also known as the *Lorm-Alphabet*), in which single letters are written onto the hand of the communication partner. Some deafblind individuals use Braille as a tactile writing and reading system. Some communicate in spoken language or may never have fully acquired a language. Regarding speech, the Tadoma method can be used to convey language input. To this end, the deafblind person touches the face of the speaker (Reed, 1996). However, this method is rarely used nowadays. For communicating in a tactile sign language, the receiver touches the hand(s) of the person who is producing the signs (Mesch, 2001). In some communities and their tactile sign languages, there is a stronger preference to follow the dominant hand only, and the positions of the hands differ between languages (Mesch, 2011, 2013; Willoughby et al., 2018). More recent research has begun to examine the emergence of a new tactile language system in the United States, called *Protactile*. Deafblind signers adapt ASL when using it through the tactile channel, resulting in the emergence of new grammatical systems in the tactile language (Edwards, 2018; Edwards and Brentari, 2020, 2021).

One might assume that the acquisition and usage of a tactile language will increase non-linguistic processing. However, to date, the specific consequences of tactile language use on other tactile perceptual processing remain unknown.

## Behavioral performance

Most studies have investigated deafblindness on the single-case level (e.g., Kawasaki et al., 1997; Janssen et al., 2007; Obretenova et al., 2010). For example, Kawasaki et al. (1997) investigated speech processing in a 74-year-old deafblind woman, who had just received a cochlear implant (CI) in her left ear. At the time of the implantation, the participant had been blind (due to retinal detachment in both eyes) and deaf in her right ear (due to a sudden hearing loss) for 9 years. Moreover, 2 years before implantation, she experienced a profound hearing loss in her left ear as well. The CI-implantation was conducted unilaterally in the left ear. Results at two and 18 months after implantation showed high vowel and consonant discrimination rates. Previous studies on cochlear implantation in deafblind individuals reported similar results (Martin et al., 1988; Ramsden et al., 1993), and the authors conclude that deafblind participants might have an outcome of the CI "similar to or better than the many sighted cochlear implant patients" (Kawasaki et al., 1997). However, it is important to note that none of these single-case studies on CI-implantation included congenitally deaf participants.

Janssen et al. (2007) focused on perceptual instead of speech processing in their single-case study. They presented a tactile perception (shape discrimination) and a memory task to a congenitally deafblind woman (40 years old) and eight hearing and sighted controls (mean age = 34.75; age range: 20–60 years). Participants in the control group were blindfolded and got noise-shielding headphones. There was no detailed report of the deafblind participant's language experience, however, the authors state that regarding informed consent, the participant, her parents, and her caregiver gave "oral and written permission" (Janssen et al., 2007). The experimental task was explained by an interpreter "through means of finger spelling in her hand" as well as "'natural gestures' (such as pointing or other commonly used hand gestures)" (Janssen et al., 2007). The results revealed an average response time of 5.3 s for the perception task and 3.2 s for the tactile memory task for the deafblind participant. Numerically, this was faster than any participant in the control group. However, when encoding speed in the memory task was taken into account, no processing advantage in the deafblind participant was observed. Moreover, more errors than in the control group occurred. No further statistical tests were performed.

Arnold and Heiron (2002) examined tactile memory in deafblind ($n = 10$; mean age = 58.8 years, age range: 35–92 years) and a sighted and hearing control group ($n = 10$; mean age = 51.4 years, age range: 25–64 years). Participants were asked to rate their current degree of deafness and blindness on a scale from 1 to 5. The ratings showed a rather high variation in sensory experiences on the individual level. Mean ratings for the degree of the sensory deprivation were 4.1 for blindness ($SD = 1.10$; range: 2–5) and 3.5 for deafness ($SD = 0.85$; range: 3–5). Only one of the deafblind participants reported an onset of deafness and blindness from birth. The etiologies of the other nine deafblind participants were not described in detail, though one of them is reported to have been diagnosed with Usher Type 2. Four tasks were conducted: A recognition task including 12 toy animal shapes, a recognition task including domino tiles, a spatial recall task, and a spatial task including matching pairs of textures on cards. Hearing controls needed more time than deafblind individuals to remember the items. Contrary to expected better performance in the deafblind participants, behavioral analyses did not reveal group differences in any of the tasks regarding accuracy. The authors suggest that this might be because, with one exception, the deafblind group included late deafblind individuals. The deafblind participants were reported to be either retired or "registered disabled" and participants' individual language experiences might have varied highly. There was no mention of language use in this group, however, the control group consisted of "five volunteers who worked with the deaf-blind on a part time basis, and five who worked in industry". The ones working with deafblind individuals had varying levels of knowledge of "the deaf-blind manual sign language" (Arnold and Heiron, 2002). Notably, the age range in the deafblind group was larger than in the control group, and language experience was not a factor that was taken into account.

A different outcome was reported in another study with a comparably high number of participants. Papagno et al. (2016) presented a spatial and a temporal tactile task to deaf ($n = 7$), blind ($n = 7$), deafblind ($n = 7$), and hearing and sighted control participants ($n = 14$). For one deafblind participant, the etiology was not clear. Due to Usher Syndrome (type 1), the other six deafblind participants had all become blind in early adulthood (mean age of onset of blindness = 16.28; range: 1–40 years); no congenitally deafblind individuals were included. One participant primarily communicated *via* the tactile Malossi system, in which letters are written on the hand. The other six deafblind participants used tactile LIS (LISt). As in Arnold and Heiron (2002), the deafblind group was older than the other groups (mean age: deafblind = 62 years, age range: 40–74 years; deaf = 45 years, age range: 27–51 years; blind = 39 years, age range: 24–50 years; controls = 44 years, age range: 28–67 years). Importantly, although being congenitally deaf, none of the deaf participants reported having acquired a signed language from birth. Only two out of seven deaf participants had learned a signed language at all—in this case, LIS. No information is provided about the specific kind of linguistic experience the other five deaf individuals had. However, all participants were reported to be using hearing aids and to be "almost fluent Italian speakers" (Papagno et al., 2016).

For the temporal task, tactile standard and target stimuli were presented to the tips of either the left or the right index finger. Target duration was 25 ms. This included three pulses of 5 ms, separated by two inter-pulse intervals (IPIs) of 5 ms. Standard duration was 15 ms, interrupted by two 5 ms long IPIs. Participants were asked to respond verbally or manually indicate if they perceived a target stimulus. In the spatial task, stimulation was presented at the index fingers and through two vibrotactile stimulators for standards and three for target stimuli. Stimulus duration was 5 ms. The deaf and deafblind groups showed better results in the spatial than the temporal task, whereas both the blind group and the control participants were better in the temporal task. Deaf and deafblind individuals displayed lower performance for temporal discrimination than the controls. The deafblind group performed better than the blind group in the spatial task. Overall, the authors concluded that the results indicate that sensory deprivation does not result in better tactile performance (Papagno et al., 2016). Again, due to the sample, it cannot be clarified whether these findings are based on sensory deprivation, linguistic experience, or both.

In a study with more complex tactile stimuli, Papagno et al. (2017) presented a short-term memory task to deaf ($n = 16$, mean age = 49.34 years, median age = 49.5, age range: 26–78 years), blind ($n = 15$; mean age = 49.34 years, median age = 56, age range: 24–77 years), deafblind ($n = 13$, mean age = 56.15 years, median age = 66, age range: 21–75 years) and sighted and hearing participants ($n = 13$; median age = 67 years). There was no difference between groups regarding age ($p = 0.54$) and years of education ($p = 0.54$). Degrees of deafness and blindness varied (severe deafness: 71–95 dB, profound deafness: >96 dB1 dB; blindness: partial, that is, with a residual visual acuity of 1/20; and total, with no light reception), and so did individual etiologies. Etiologies of deafblind participants included, *inter alia*, Usher syndrome, Poliomyelitis, Norrie syndrome, KID syndrome, and repeated otitis. No congenitally deafblind individuals were included. All but one deafblind participant were users of Braille (mean age of acquisition = 9.25 years; range: 1–24 years). None of the deaf and deafblind participants had acquired a (tactile) signed language from birth; some participants never acquired one. The mean age of acquisition for LISt in the deafblind group (LISt users: $n = 8$) was 12.59 years (range: 6–35 years). Mean age of LIS acquisition in the deaf LIS users ($n = 14$) was 6.5 years (range: 3–20 years).

To examine short-term memory, the authors presented a task with checkerboard patterns of different sizes with either rough or smooth surfaces. Participants were presented with three patterns for each size (starting with the smallest) for 10 s and then asked to recreate the pattern. The experimental session ended if a participant did not pass two out of the three trials. Behavioral measures included completion time, number of correctly filled matrices, size of the largest completed matrix, and tactile span. The results revealed no difference between blind, deafblind, and deaf participants. In contrast to other studies (e.g., Arnold and Heiron, 2002), there was no difference between those groups and the control group regarding completion time. The deaf and the blind group outperformed the controls in all other behavioral measurements, whereas the deafblind group only showed a statistical tendency for better performance in the number of correctly reproduced matrices ($p = 0.063$). Performance and age of acquisition of Braille were negatively correlated in the deafblind and blind groups, pointing to an impact of Braille experience on tactile short-term memory skills. Notably, LISt acquisition, the onset of deafness (in deaf and deafblind participants), and blindness (in blind and deafblind participants) were not correlated with task performance. No correlation analysis including LIS acquisition was reported.

Most deafblind participants from Papagno et al. (2016, 2017) also participated in a behavioral study by Cattaneo et al. (2018), investigating bilateral haptic spatial attention. While a group of early deaf individuals (signers of LIS and non-signers) did not show a bias to shift to the left or right side from a veridical midpoint in the line bisection task, deafblind participants displayed a bias to the left side. This result was in accordance with the behavioral outcomes of early blind participants as well as a hearing and sighted control group. This points to different processing mechanisms as a function of unisensory and bisensory sensory deprivation, respectively, and the impact of visual experience in the deaf individuals.

### Neuroscientific results

Osaki et al. (2004) examined the processing of tactile words and non-words in an MEG study with a 38-year-old male participant, who had become deafblind at the age of 35 years. The participant had started learning a tactile language (presentation of Japanese characters to the hand) two years before the study took place. His data was compared to six hearing and sighted controls (mean age = 30.3 years, age range: 24–45 years). During the session, nouns (comprising three characters) and non-words were presented to the right hand. The analyses revealed activation in left IFG, left middle occipital gyrus, and left posterior superior temporal gyrus following the tactile word condition—but not the non-word stimuli—in the deafblind participant. These results were confirmed by an additional positron emission tomography (PET). The hearing participants showed varying patterns of activation in the same areas after being presented with tactile words.

In a single-case fMRI study, Obretenova et al. (2010) examined the neural processing of Braille, Print on Palm (POP), and haptic ASL (hASL). The deafblind male participant was born deaf and became blind at the age of 6 years (due to bilateral ocular trauma). For communication, he used Braille, POP, and hASL which he started acquiring around the age of 10 years. A 24-year-old, hearing and sighted female was recruited as a control participant. She reported having had 3 years of experience with hASL due to training to become an ASL interpreter for deafblind individuals, but she did not know POP or Braille. For the deafblind participant, each of the three input types (Braille, POP, hASL), words, and non-words were presented to the left hand (as preferred by the participant). Moreover, the experimental conditions included rest as well. For the control participant, only hASL (and rest) were investigated. Each trial was 3 s long (with six presentations per block). As an experimental task, participants were asked to decide whether the presented words started with a consonant or a vowel. There were no differences between the participants regarding behavioral performance in hASL (both achieved an accuracy of 78.1%). For the deafblind participant, the fMRI results showed enhanced activation for the three input types in left inferior frontal and posterior superior temporal language areas. Moreover, the deafblind participant displayed increased bilateral activation in occipital cortex. A diffusion tensor imaging-based tractography revealed stronger connectivity between occipital and temporal areas in the deafblind participant. The control participant showed increased activation following hASL input in left inferior frontal areas and, although less strongly, in posterior superior temporal language areas. However, no comparable increase in activation was observed in occipital areas. These findings are consistent with the assumption of crossmodal plasticity as a result of sensory deprivation in the deafblind participant (see Auer et al., 2007; Bedny et al., 2011).

### Summary: deafblind participants

For deafblind individuals, the lack of research on somatosensory processing is even more substantial than for deaf individuals. Overall, the consequences of deafblindness on the processing of touch remain mostly inconclusive, and sometimes, findings from different studies are providing conflicting information. Moreover, for this group, it is particularly important to consider the impact of possible comorbidities. One might expect a difference as a function of sensory and/or linguistic experience, but at this point, this assumption remains partly speculative. To identify the impact of individual experience on brain development and neuroplasticity, different groups of individuals should be identified and tested in similar experimental paradigms. Notably, while the studies with deaf individuals focused on congenitally and early deaf participants, the literature review on deafblind individuals was mostly limited to research concerning individuals who experienced a late onset of (deaf) blindness.

## Discussion

This review addresses existing studies on the processing of touch and associated crossmodal plasticity in deaf and deafblind individuals. To date, little is known about the development of the somatosensory system in these groups. Regarding the consequences of deafness, the processing of touch has received less attention than the visual system. Even fewer studies exist that are investigating the sensory development of deafblind individuals, for whom touch is the only sense that can ensure communication.

Some of the few published studies to date point to an altered processing as well as a crossmodal reorganization in both deaf and deafblind individuals (e.g., Levänen et al., 1998; Obretenova et al., 2010; Karns et al., 2012). These changes are expressed on behavioral and neural levels. Thus, deafness and deafblindness appear to impact somatosensory (and in the case of deafness, also multisensory) processing to some extent. However, studies on visual processing in deaf individuals have shown that sensory deprivation does not result in general enhancements or deficits of processing abilities in the remaining senses. Instead, group differences depend on stimulus features and the investigated perceptual functions. For example, deaf participants have been shown to outperform hearing groups in simple detection, but not discrimination of visual stimuli (for reviews see Bavelier et al., 2006; Pavani and Bottari, 2012). Moreover, considering motion as a relevant stimulus feature for early deaf individuals is supported by previously observed altered visual motion detection abilities compared to hearing controls (Parasnis and Samar, 1985; Neville and Lawson, 1987a; Armstrong et al., 2002; Proksch and Bavelier, 2002). Deaf participants have displayed enhanced behavioral performance and larger neural responses than hearing individuals to peripheral than focal stimulation (e.g., Neville et al., 1983; Neville and Lawson, 1987a; Bottari et al., 2010, 2011). Furthermore, the interplay of the visual and the tactile modality seems to be altered in congenitally deaf signers (Karns et al., 2012; Hauthal et al., 2015; Villwock et al., 2022). Regarding studies including tactile stimulation, different stimuli features and perceptual functions such as spatial and temporal processing have been investigated. However, the findings have not always been consistent, and often, the sample sizes are quite small. This poses a challenge concerning the interpretation of these studies' results.

Investigating the specific sensory experience of an individual allows the identification of determinants for neuroplastic changes as a function of sensory deprivation. For example, due to the higher degree of neuroplasticity in ontogeny, and the impact of critical periods on the developmental trajectory, the age of deprivation onset is considered a very important factor for perceptual and linguistic development (Knudsen, 2004; Mayberry and Kluender, 2017). In some of the existing studies on somatosensory processing, deaf and deafblind participants were older than controls (e.g., Arnold and Heiron, 2002; Papagno et al., 2016). This must be considered when interpreting results from these studies—previous work has shown higher thresholds in hearing seniors (> 60 years of age), indicating an age effect on these kinds of tactile processing skills (see, e.g., Brown and Sainsbury, 2000).

Importantly, some changes in behavioral outcomes might be associated with language experience instead of the sensory deprivation (see Emmorey et al., 1993, for better performance in visual mental rotation in deaf and hearing signers compared to hearing non-signers). Although studies have shown that the language network is mostly identical for spoken and signed languages, there are some modality-specific differences. For example, complex syntactic processing seems to be modality-independent and can be localized in the anterior and posterior superior temporal sulci (aSTS, pSTS) for both signed and spoken languages (Matchin et al., 2022). On the contrary, the supramarginal gyrus (SMG) is more active for signed than for spoken word production (Emmorey et al., 2002, 2007).

Van Dijk et al. (2013a) observed better tactile spatial configuration abilities for both deaf and hearing signers compared to hearing non-signers. Thus, the critical factor for altered processing here is not sensory deprivation, but language experience (all hearing participants were proficient signers). In a study by the same authors (Van Dijk et al., 2013b) on haptic spatial orientation abilities, it was the deaf group that outperformed hearing signers and non-signers indicating that for this type of processing, perceptual abilities change as a function of sensory deprivation.

Moreover, studies have revealed modality specific differences for changes in performance. Contrary to enhancements in visual detection tasks for congenitally and early deaf individuals, Heimler and Pavani (2014) did not find any behavioral differences to hearing controls in similar tasks in the tactile modality. Notably, none of their participants acquired a signed language from birth or in early childhood. Frenzel et al. (2012) report worse performance in tactile sensitivity in a young group of deaf participants. However, the lack of information on the participants' background impedes a further interpretation of the results.

However, sometimes, findings from studies with different stimulus modalities are consistent. Pavani and Bottari (2012) point to an advantage of deaf compared to hearing individuals for visual detection, but discuss how in the visual modality, discrimination tasks tend to result in comparable outcomes in deaf and hearing groups instead. While Levänen and Hamdorf (2001) reported behavioral enhancements of congenitally deaf signers compared to hearing controls in the detection of tactile frequency changes, no group differences were observed in a tactile frequency discrimination task. This is in accordance with findings from a haptic spatial discrimination task in a study by Bolognini et al. (2012). Regarding the impact of neuroplasticity on the development of different perceptual functions, Cardin et al. (2020) argue that functional preservation and change must not rule each other out—instead, they might be based on different and yet simultaneously existing neural mechanisms (see also Land et al., 2016).

An interesting case of somatosensory processing in deaf and deafblind individuals are temporal tasks. Several studies have pointed to neural differences regarding spatial vs. temporal processing and the assumption that compared to hearing individuals, deaf individuals might show disadvantages in temporal processing (e.g., Heming and Brown, 2005; Bolognini et al., 2010, 2012; Papagno et al., 2016; Zimmermann et al., 2021).

Bolognini et al. (2012) found a correlation between auditory cortex involvement latency and behavioral performance in a temporal task. Later recruitment of auditory areas (as observed in the hearing control group) was associated with better behavioral outcomes. Following the *perceptual deficiency theory,* the authors argue that for the typical development of temporal processing skills, early auditory experience is needed. From this point of view, the earlier involvement of the STG for both tasks in the deaf group, as opposed to the later and specific activation for the temporal task in hearing individuals, would indicate a lack of crossmodal compensation as a result of deafness (see Scurry et al., 2020b, for fMRI results on lower proportions of directionally tuned voxels in primary somatosensory cortex in deaf compared to hearing individuals).

Other studies have reported similar behavioral outcomes for deaf and hearing groups in temporal processing (Bross and Sauerwein, 1980; Poizner and Tallal, 1987; Nava et al., 2008; Moallem et al., 2010). Identifying the critical factors for these differences in behavioral outcomes poses a challenge. Regarding their sensory experiences, the included samples of deaf individuals appear to be rather homogenous—all of them reported a congenital or early onset of deafness. Importantly, though, their linguistic experiences are not always available in full detail. For example, Heming and Brown (2005) describe that all deaf participants reported ASL as their first language—however, no further information on their actual age of acquisition is provided. Bolognini et al. (2012) included nine congenitally deaf participants in their temporal task. While two of them did not know a signed language, the other seven had acquired LIS before the age of 3 years. However, some of them grew up in hearing families and learned LIS in school, and it is not traceable what their daily linguistic experience in school and at home looked like.

The arguments by Bolognini et al. (2012) concerning a decrease in temporal perception skills as a function of auditory deprivation are supported by findings by Papagno et al. (2016). Here, congenitally deaf and late deafblind individuals both displayed better performance in spatial, but lower performance in temporal discrimination than the controls. However, no congenitally deafblind individuals were included—it could be speculated that their somatosensory perception is more enhanced than in sighted and late blind deaf individuals. Comparing congenitally and late deafblind individuals in the same experimental design would allow for an investigation of the impact of bisensory deprivation from birth versus the loss of a second sensory system later in life. Moreover, none of the deaf participants in the study had acquired a signed language from birth, and only two learned one later in life.

Sharp et al. (2018) showed higher error rates in crossed vs. uncrossed arms conditions in a tactile TOJ task. They suggest that this is due to difficulties in integrating the conflicting visual and somatosensory information in the deaf group. While the participants were congenitally deaf, only one out of 13 participants was a user of a signed language. Thus, it might be possible that the poorer performance of deaf participants in temporal tasks such as the TOJ conducted by Sharp et al. (2018) is due to a delay in first language acquisition and its impact on other cognitive functions. In deaf signers, one might expect an increased ability to navigate the crossed arms condition instead.

Space is a critical factor in sign language production and perception (Mathur and Rathmann, 2012; Shield and Meier, 2018). Deaf (and hearing) signers display advantages in spatial processing, such as mental rotation skills (Emmorey et al., 1993; Kubicek and Quandt, 2021). Because signers do not get visual feedback from their own language production, they rely more on somatosensory feedback and proprioception compared to speech production (Emmorey et al., 2009). For deafblind language users, tactile sign languages and tactile communication systems are perceived and produced through the somatosensory modality by the conveyer and the receiver (Edwards and Brentari, 2020, 2021). Papagno et al. (2016) argue that "discriminative touch is not so relevant in humans, while social touch is." Thus, for individuals who have acquired a visual-gestural or tactile signed language within the significant time windows of brain development, a significantly decreased performance in tactile processing would be unexpected—in particular for spatial, but also temporal tasks. Yet, some previous studies have pointed to opposite findings (e.g., Bolognini et al. 2012). It has been argued that when compared to vision and audition, touch is often underestimated regarding its information content (Gallace and Spence, 2014). Unlike the visual modality, the tactile modality has a high temporal resolution as well, and thus, the somatosensory system should provide reliable temporal information to deaf and deafblind individuals. Therefore, to explain the results in temporal tasks, it is crucial to address the role of language modality and acquisition on behavioral differences and neural changes in deaf and deafblind individuals compared to control groups. To date, especially, but not only the impact of acquiring and using a tactile sign language on other somatosensory perceptual functions remains inconclusive (Edwards, 2018). Clearly, more studies are needed to address this gap in the literature.

In tasks on tactile memory skills, the outcomes of several studies did not reveal a consistent pattern, either. Arnold and Heiron (2002) observed a faster completion time in deafblind compared to hearing participants, but similar accuracy outcomes. Notably, the etiologies and language backgrounds of the included deafblind individuals is not explained in detail. Papagno et al. (2017) did not find response time differences between deaf, blind, deafblind, and control participants, but the deaf and blind groups outperformed the controls in all other behavioral measurements. For the blind and deafblind groups, performance and age of Braille acquisition were negatively correlated, indicating Braille experience as an impacting factor for tactile short-term memory skills. Task performance was not correlated with onset of deafness (in deaf and deafblind participants) and blindness (in blind and deafblind participants). No correlation was found including LISt acquisition, however, only eight out of the 15 participants had learned LISt, and no information on their early language experiences is available. None of the deaf individuals acquired a signed language from birth, some never did. Thus, it could be speculated that at least some participants did experience a delayed acquisition of a first language. In a single-case study including a congenitally deafblind woman, Janssen et al. (2007)

reported similar response time and more errors in tests compared to hearing controls in a tactile memory task.

For deaf participants, alterations in performance and neural responses have been found for multisensory processing, indicating neuroplasticity as a result of auditory deprivation (e.g., Karns et al., 2012; Hauthal et al., 2015; Villwock et al., 2022). Different behavioral outcomes in deaf compared to hearing groups have been demonstrated for static (e.g., Karns et al. 2012) and dynamic visuo-tactile stimulation (Villwock et al., 2022). Regarding neural responses in somatosensory processing, several studies have indicated signs of intramodal and crossmodal plasticity as a function of deafness (e.g., Levänen et al., 1998; Auer et al., 2007; Bolognini et al., 2012; Karns et al., 2012; Villwock et al., 2022; but see Hickok et al., 1997). For simple static stimulation, these patterns were observed in participants with different language backgrounds (Levänen et al., 1998; Auer et al., 2007). In a task including congruent and incongruent motion stimuli, Villwock et al. (2022) observed a more anterior distribution of the electrophysiological response as well as differences in the latency and the lateralization of a motion congruency effect. Because the participants were all congenitally deaf and acquired a signed language from birth, it cannot be concluded whether these differences are based on the experience of deafness, sign language usage, or both.

For deafblind individuals, two studies examining the neural response to tactile language input (Braille, Print on Palm, and hASL) revealed enhanced activation of language areas in a late deafblind (MEG study; Osaki et al., 2004), and in a congenitally deafblind and a sighted hearing participant (fMRI study; Obretenova et al., 2010). Moreover, Obretenova et al. (2010) observed increased bilateral activation in occipital cortex as well as enhanced occipital-temporal connectivity in the deafblind participant, but not the hearing user of hASL. This points to changes as a result of crossmodal plasticity, which is in accordance with findings of enhanced activation in auditory areas following tactile stimulation in deaf (e.g., Levänen et al., 1998; Karns et al., 2012), and in visual areas as a response to auditory stimulation in blind individuals (e.g., Bedny et al., 2011).

Taken together, the pattern is not clear, and sometimes, different outcomes were observed in very similar tasks. These inconsistencies may be due to a high variance regarding samples of deaf and deafblind participants and their sensory as well as linguistic experiences (Bavelier and Neville, 2002; Dye and Hauser, 2014). To shed light on sensory processing after auditory and audio-visual deprivation, future studies need to thoroughly distinguish between possible influencing factors. In some studies, participants were congenitally deaf or deafblind, whereas, in others, they had become deaf, blind, or deafblind later in life. Some acquired a language from birth, and these languages included, *inter alia*, (tactile) signed languages, spoken languages, and Braille. Some participants experienced a delayed acquisition of a first language. Some used a signed system based on the grammar of a spoken language (such as signed exact English, SEE), and some were non-signers. Keeping the diversity of the included samples in mind is crucial to identifying the deciding factors for possible differences in the neural response and behavioral outcomes.

In some cases, findings might have been misinterpreted due to a lack of information about the participants' individual backgrounds. This could include sensory as well as linguistic experiences. A perspicuous example regarding language experience comes from previous work on selective attention in deaf children (for a review, see Dye and Bavelier, 2010). Several studies seemed to support the view that deafness negatively impacted attentional skills in children (e.g., Quittner et al., 1994; Smith et al., 1998). However, when the samples of children were controlled for language background, the results turned out differently. For example, in a visual–spatial attention task, a similar performance was observed in hearing children and deaf children who had learned a language from birth—in this case, ASL (Dye et al., 2009). Therefore, the individual language experiences of participants must be considered.

Importantly, only a minority of deaf children are born into deaf, signing families (approx. 5%, see Mitchell and Karchmer, 2004). They tend to grow up with a signed language, experience a typical language acquisition from birth, display fewer comorbidities, and have a smaller probability of undergoing neurological trauma (Dye and Bavelier, 2013; Lillo-Martin and Henner, 2021). On the other end of the language acquisition continuum, there are individuals who might never experience full access to a language. Deaf children born into hearing, non-signing families can be at risk of experiencing delayed first language exposure and atypical social communication (Dye and Bavelier, 2013; Wilkinson and Morford, 2020). Language deprivation has consequences on emotional, linguistic, and cognitive development (Mayberry et al., 2002; Morford, 2003; Humphries et al., 2012). Moreover, without input, some neural networks associated with language processing cannot typically develop (Mayberry et al., 2011). For example, the usual dominance of the left hemisphere as observed in deaf individuals acquiring a signed language early in life does not seem to occur in very late learners of a first language (Ferjan Ramirez et al., 2014). These findings point to a change in neural circuits involved in language processing after severe language deprivation. While the risk of delayed exposure to a first language is still a highly relevant issue for deaf children today (Wilkinson and Morford, 2020; Villwock et al., 2021), the situation is even more alarming for children who are born deafblind (Edwards and Brentari, 2021). Therefore, participants from these groups will display highly variable linguistic backgrounds.

Most experimental studies with deaf and deafblind individuals have followed a purely quantitative approach for collecting participants' information, using questionnaires and surveys with often rather limited content. However, especially for deafblind participants, even a very thorough quantitative approach may not be sufficient to fully capture an individual's experience. Instead, a deeper qualitative investigation on the single-case level would be needed. This points to two important considerations: First, to draw general clear conclusions, the included samples need to be as homogenous as possible concerning their sensory experiences and etiologies, and different groups of participants performing the same task should be included in studies. Second, the individual language backgrounds of the participants must be taken into account. For example, testing somatosensory processing in deaf L1M1 signers might not be enough to understand how deaf individuals process input from the environment. Furthermore, too often, a deficit-oriented point of view might have resulted in a lack of studies on, for example, tactile languages (Henner 2022).

## Conclusion

To conclude, when conducting studies on the processing of touch with deaf and deafblind individuals, a thorough investigation of individual experiences is crucial for explaining the results. Including such measures could shed light on the reasons for possible changes concerning the remaining sensory modalities—that is, for neuroplasticity. Importantly, the participants' etiologies, as well as their language backgrounds, need to be considered in more detail. This review of the current research on basic perceptual functions in deaf and deafblind individuals focused on behavioral outcomes and crossmodal plasticity. It demonstrates that neither sensory nor linguistic backgrounds alone provide sufficient knowledge about an individual's experience. To date, the results do not provide a clear picture, and sometimes, findings from different studies with rather similar tasks show conflicting information. Hence, the impact of deafness and deafblindness on the processing of touch remains not well understood. Given the highly variable language backgrounds in deaf and deafblind communities, examining individual experiences is crucial in order to understand the development of the somatosensory system. For example, delayed access to a first language, and even more so a serious language deprivation may have an impact on other, basic perceptual functions. Ideally, studies should aim to include clearly defined groups of participants and apply similar tasks to samples with different sensory and linguistic experiences. Including a broad range of participants is demanding, but important to identify the deciding factors for possible differences in the neural response and behavioral outcomes. This comprehensive perspective can be considered to strategically disentangle the impact of sensory experience (deprivation) and language experience on basic sensory processing—and vice versa. By providing novel information on the connection between perceptual functions and individual experience, it can contribute to a better understanding of the human brain and its plasticity.

## Author contributions

AV wrote the first draft of the manuscript. KG and AV wrote sections of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

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## References

Allen, J. S., Emmorey, K., Bruss, J., and Damasio, H. (2013). Neuroanatomical differences in visual, motor, and language cortices between congenitally deaf signers, hearing signers, and hearing non-signers. *Front. Neuroanat.* 7, 1–10. doi: 10.3389/fnana.2013.00026

Allman, B. L., Keniston, L. P., and Meredith, M. A. (2009). Adult deafness induces somatosensory conversion of ferret auditory cortex. *Proc. Natl. Acad. Sci. U. S. A.* 106, 5925–5930. doi: 10.1073/pnas.0809483106

Almeida, A. J., He, D., Chen, Q., and Mahon, B. Z. (2015). Decoding visual location from neural patterns in the auditory cortex of the congenitally deaf. *Psychol. Sci.* 26, 1771–1782. doi: 10.1177/0956797615598970

Armstrong, B. A., Neville, H. J., Hillyard, S. A., and Mitchell, T. V. (2002). Auditory deprivation affects processing of motion, but not color. *Cogn. Brain Res.* 14, 422–434. doi: 10.1016/S0926-6410(02)00211-2

Arnold, P., and Heiron, K. (2002). Tactile memory of deaf-blind adults on four tasks. *Scand. J. Psychol.* 43, 73–79. doi: 10.1111/1467-9450.00270

Auer, E. T. Jr., Bernstein, L. E., Sungkarat, W., and Singh, M. (2007). Vibrotactile activation of the auditory cortices in deaf versus hearing adults. *NeuroReport* 18, 645–648. doi: 10.1097/WNR.0b013e3280d943b9

Bavelier, D., Brozinsky, C., Tomann, A., Mitchell, T., Neville, H., and Liu, G. (2001). Impact of early deafness and early exposure to sign language on the cerebral organization for motion processing. *J. Neurosci.* 21, 8931–8942. doi: 10.1523/JNEUROSCI.21-22-08931.2001

Bavelier, D., Dye, M. W. G., and Hauser, P. C. (2006). Do deaf individuals see better? *Trends Cogn. Sci.* 10, 512–518. doi: 10.1016/j.tics.2006.09.006

Bavelier, D., and Neville, H. J. (2002). Cross-modal plasticity: where and how? *Nat. Rev. Neurosci.* 3, 443–452. doi: 10.1038/nrn848

Bedny, M., Pascual-Leone, A., Dodell-Feder, D., Fedorenko, E., and Saxe, R. (2011). Language processing in the occipital cortex of congenitally blind adults. *Proc. Natl. Acad. Sci.* 108, 4429–4434. doi: 10.1073/pnas.1014818108

Benetti, S., Zonca, J., Ferrari, A., Rezk, M., Rabini, G., and Collignon, O. (2021). Visual motion processing recruits regions selective for auditory motion in early deaf individuals. *NeuroImage* 230:117816. doi: 10.1016/j.neuroimage.2021.117816

Benetti, S., van Ackeren, M. J., Rabini, G., Zonca, J., Foa, V., Baruffaldi, F., et al. (2017). Functional selectivity for face processing in the temporal voice area of early deaf individuals. *Proc. Natl. Acad. Sci. U. S. A.* 114, E6437–E6446. doi: 10.1073/pnas.1618287114

Berger, C., Kühne, D., Scheper, V., and Kral, A. (2017). Congenital deafness affects deep layers in primary and secondary auditory cortex. *J. Comp. Neurol.* 525, 3110–3125. doi: 10.1002/cne.24267

Bola, Ł., Zimmermann, M., Mostowski, P., Jednoróg, K., Marchewka, A., Rutkowski, P., et al. (2017). Task-specific reorganization of the auditory cortex in deaf humans. *Proc. Natl. Acad. Sci. U. S. A.* 114, E600–E609. doi: 10.1073/pnas.1609000114

Bolognini, N., Cecchetto, C., Geraci, C., Maravita, A., Pascual-Leone, A., and Papagno, C. (2012). Hearing shapes our perception of time: temporal discrimination of tactile stimuli in deaf people. *J. Cogn. Neurosci.* 24, 276–286. doi: 10.1162/jocn_a_00135

Bolognini, N., Papagno, C., Moroni, D., and Maravita, A. (2010). Tactile temporal processing in the auditory cortex. *J. Cogn. Neurosci.* 22, 1201–1211. doi: 10.1162/jocn.2009.21267

Bosworth, R. G., and Dobkins, K. R. (1999). Left-hemisphere dominance for motion processing in deaf signers. *Psychol. Sci.* 10, 256–262. doi: 10.1111/1467-9280.00146

Bosworth, R. G., and Dobkins, K. R. (2002). The effects of spatial attention on motion processing in deaf signers, hearing signers, and hearing nonsigners. *Brain Cogn.* 49, 152–169. doi: 10.1006/brcg.2001.1497

Bottari, D., Bednaya, E., Dormal, G., Villwock, A., Dzhelyova, M., Grin, K., et al. (2020). EEG frequency-tagging demonstrates increased left hemispheric involvement and crossmodal plasticity for face processing in congenitally deaf signers. *NeuroImage* 223:117315. doi: 10.1016/j.neuroimage.2020.117315

Bottari, D., Caclin, A., Giard, M.-H., and Pavani, F. (2011). Changes in early cortical visual processing predict enhanced reactivity in deaf individuals. *PLoS One* 6:e25607. doi: 10.1371/journal.pone.0025607

Bottari, D., Heimler, B., Caclin, A., Dalmolin, A., Giard, M.-H., and Pavani, F. (2014). Visual change detection recruits auditory cortices in early deafness. *NeuroImage* 94, 172–184. doi: 10.1016/j.neuroimage.2014.02.031

Bottari, D., Nava, E., Ley, P., and Pavani, F. (2010). Enhanced reactivity to visual stimuli in deaf individuals. *Restor. Neurol. Neurosci.* 28, 167–179. doi: 10.3233/RNN-2010-0502

Bross, M., and Sauerwein, H. (1980). Signal detection of visual flicker in deaf and hearing individuals. *Percept. Mot. Skills* 51, 839–843. doi: 10.2466/pms.1980.51.3.839

Brown, L. N., and Sainsbury, R. S. (2000). Hemispheric equivalence and age-related differences in judgments of simultaneity to somatosensory stimuli. *J. Clin. Exp. Neuropsychol.* 22, 587–598. doi: 10.1076/1380-3395(200010)22:5;1-9;FT587

Campbell, R., MacSweeney, M., and Waters, D. (2008). Sign language and the brain: a review. *J. Deaf. Stud. Deaf. Educ.* 13, 3–20. doi: 10.1093/deafed/enm035

Cardin, V., Grin, K., Vinogradova, V., and Manini, B. (2020). Crossmodal reorganisation in deafness: mechanisms for functional preservation and functional change. *Neurosci. Biobehav. Rev.* 113, 227–237. doi: 10.1016/j.neubiorev.2020.03.019

Cattaneo, Z., Rinaldi, L., Geraci, C., Cecchetto, C., and Papagno, C. (2018). Spatial biases in deaf, blind, and deafblind individuals as revealed by a haptic line bisection task. *Q. J. Exp. Psychol. (Hove)* 71, 2325–2333. doi: 10.1177/1747021817741288

Chakravarty, A. (1968). Influence of tactual sensitivity on tactual localization, particularly of deaf children. *J. Gen. Psychol.* 78, 219–221. doi: 10.1080/00221309.1968.9710435

Curtiss, S. (1977). *Genie*, A Psycholinguistic Study of a Modern-Day "Wild Child." Perspectives in Neurolinguistics and Psycholinguistics, Academic Press.

Dammeyer, J. (2010). Prevalence and aetiology of congenitally deafblind people in Denmark. *Int. J. Audiol.* 49, 76–82. doi: 10.3109/14992020903311388

Dammeyer, J. (2013). Characteristics of a Danish population of acquired deafblindness. *Br. J. Vis. Impair.* 31, 189–197. doi: 10.1177/0264619613490518

Dewey, R. S., and Hartley, D. E. H. (2015). Cortical cross-modal plasticity following deafness measured using functional near-infrared spectroscopy. *Hear. Res.* 325, 55–63. doi: 10.1016/j.heares.2015.03.007

Dormal, G., and Collignon, O. (2011). Functional selectivity in sensory-deprived cortices. *J. Neurophysiol.* 105, 2627–2630. doi: 10.1152/jn.00109.2011

Dye, M. W. G., and Bavelier, D. (2010). Attentional enhancements and deficits in deaf populations: an integrative review. *Restor. Neurol. Neurosci.* 28, 181–192. doi: 10.3233/RNN-2010-0501

Dye, M. W. G., and Bavelier, D. (2013). "Visual attention in deaf humans: a neuroplasticity perspective," in *Deafness*. eds. A. Kral, A. Popper and R. Fay, Springer Handbook of Auditory Research, vol. *47* (New York, NY: Springer).

Dye, M. W. G., and Hauser, P. C. (2014). Sustained attention, selective attention and cognitive control in deaf and hearing children. *Hear. Res.* 309, 94–102. doi: 10.1016/j.heares.2013.12.001

Dye, M. W. G., Hauser, P. C., and Bavelier, D. (2009). Is visual selective attention in deaf individuals enhanced or deficient? The case of the useful field of view. *PLoS One* 4:e5640. doi: 10.1371/journal.pone.0005640

Edwards, T. (2018). Re-channeling language: the mutual restructuring of language and infrastructure among DeafBlind people at Gallaudet university. *J. Linguist. Anthropol.* 28, 273–292. doi: 10.1111/jola.12199

Edwards, T., and Brentari, D. (2021). The grammatical incorporation of demonstratives in an emerging tactile language. *Front. Psychol.* 11:579992. doi: 10.3389/fpsyg.2020.579992

Edwards, T., and Brentari, D. (2020). Feeling phonology: the conventionalization of phonology in protactile communities in the United States. *Language* 96, 819–840. doi: 10.1353/lan.2020.0063

Emmorey, K., Bosworth, R., and Kraljic, T. (2009). Visual feedback and self-monitoring of sign language. *J. Mem. Lang.* 61, 398–411. doi: 10.1016/j.jml.2009.06.001

Emmorey, K., Damasio, H., McCullough, S., Grabowski, T., Ponto, L. L., Hichwa, R. D., et al. (2002). Neural systems underlying spatial language in American sign language. *NeuroImage* 17, 812–824. doi: 10.1006/nimg.2002.1187

Emmorey, K., Mehta, S., and Grabowski, T. J. (2007). The neural correlates of sign versus word production. *NeuroImage* 36, 202–208. doi: 10.1016/j.neuroimage.2007.02.040

Emmorey, K., McCullough, S., Mehta, S., and Grabowski, T. J. (2014). How sensory-motor systems impact the neural organization for language: direct contrasts between spoken and signal language. *Front. Psychol.* 5:484. doi: 10.3389/fpsyg.2014.00484

Emmorey, K., Kosslyn, S. M., and Bellugi, U. (1993). Visual imagery and visual-spatial language: enhanced imagery abilities in deaf and hearing ASL signers. *Cognition* 46, 139–181. doi: 10.1016/0010-0277(93)90017-P

Ferjan Ramirez, N., Leonard, M. K., Davenport, T. S., Torres, C., Halgren, E., and Mayberry, R. I. (2014). Neural language processing in adolescent first-language learners: longitudinal case studies in American sign language. *Cereb. Cortex* 26, 1015–1026. doi: 10.1093/cercor/bhu273

Fine, I., Finney, E. M., Boynton, G. M., and Dobkins, K. R. (2005). Comparing the effects of auditory deprivation and sign language within the auditory and visual cortex. *J. Cogn. Neurosci.* 17, 1621–1637. doi: 10.1162/089892905774597173

Finney, E. M., Clementz, B. A., Hickok, G., and Dobkins, K. R. (2003). Visual stimuli activate auditory cortex in deaf subjects: evidence from MEG. *NeuroReport* 14, 1425–1427. doi: 10.1097/00001756-200308060-00004

Finney, E. M., Fine, I., and Dobkins, K. R. (2001). Visual stimuli activate auditory cortex in the deaf. *Nat. Neurosci.* 4, 1171–1173. doi: 10.1038/nn763

Frenzel, H., Bohlender, J., Pinsker, K., Wohlleben, B., Tank, J., Lechner, S. G., et al. (2012). A genetic basis for mechanosensory traits in humans. *PLoS Biol.* 10:e1001318. doi: 10.1371/journal.pbio.1001318

Gallace, A., and Spence, C. (2014). *In Touch With the Future: The Sense of Touch from Cognitive Neuroscience to Virtual Reality*. Oxford: Oxford University Press. doi:10.1093/acprof:oso/9780199644469.001.0001

Gilbert, C. D., Sigman, M., and Crist, R. E. (2001). The neural basis of perceptual learning review. *Neuron* 31, 681–697. doi: 10.1016/S0896-6273(01)00424-X

González-Garrido, A. A., Ruiz-Stovel, V. D., Gómez-Velázquez, F. R., Vélez-Pérez, H., Romo-Vázquez, R., Salido-Ruiz, R. A., et al. (2017). Vibrotactile discrimination training affects brain connectivity in profoundly deaf individuals. *Front. Hum. Neurosci.* 11:28. doi: 10.3389/fnhum.2017.00028

Hauthal, N., Debener, S., Rach, S., Sandmann, P., and Thorne, J. D. (2015). Visuo-tactile interactions in the congenitally deaf: a behavioral and event-related potential study. *Front. Integr. Neurosci.* 8:98. doi: 10.3389/fnint.2014.00098

Heimler, B., and Pavani, F. (2014). Response speed advantage for vision does not extend to touch in early deaf adults. *Exp. Brain Res.* 232, 1335–1341. doi: 10.1007/s00221-014-3852-x

Heimler, B., Weisz, N., and Collignon, O. (2014). Revisiting the adaptive and maladaptive effects of crossmodal plasticity. *Neuroscience* 283, 44–63. doi: 10.1016/j.neuroscience.2014.08.003

Heming, J. E., and Brown, L. N. (2005). Sensory temporal processing in adults with early hearing loss. *Brain Cogn.* 59, 173–182. doi: 10.1016/j.bandc.2005.05.012

Henner, J. [@jmhenner]. (2022). Haptic/tactile languages are severely understudied in linguistics probably because of the association with disability thread attached tweet. Twitter. https://twitter.com/jmhenner/status/1519636421732188160

Hickok, G., Poeppel, D., Clark, K., Buxton, R. B., Rowley, H. A., and Roberts, T. P. (1997). Sensory mapping in a congenitally deaf subject: MEG and fRMI studies of cross-modal non-plasticity. *Hum. Brain Mapp.* 5, 437–444. doi: 10.1002/(SICI)1097-0193(1997)5:6<437::AID-HBM4>3.0.CO;2-4

Humphries, T., Kushalnagar, P., Mathur, G., Napoli, D., Padden, C., Rathmann, C., et al. (2012). Language acquisition for deaf children: reducing the harms of zero tolerance to the use of alternative approaches. *Harm Reduct. J.* 9:16. doi: 10.1186/1477-7517-9-16

Hötting, K., and Röder, B. (2004). Hearing cheats touch, but less in congenitally blind than in sighted individuals. *Psychol. Sci.* 15, 60–64. doi: 10.1111/j.0963-7214.2004.01501010.x

Hötting, K., Rösler, F., and Röder, B. (2004). Altered auditory-tactile interactions in congenitally blind humans: an event-related potential study. *Exp. Brain Res.* 159, 370–381. doi: 10.1007/s00221-004-1965-3

Janssen, M. J., Nota, S., Eling, P. A., and Ruijssenaars, W. A. (2007). The advantage of encoding tactile information for a woman with congenital deaf-blindness. *J. Vis. Impair. Blind.* 101, 653–657. doi: 10.1177/0145482X0710101011

Karns, C. M., Dow, M. W., and Neville, H. J. (2012). Altered cross-modal processing in the primary auditory cortex of congenitally deaf adults: a visual-somatosensory fMRI study with a double-flash illusion. *J. Neurosci.* 32, 9626–9638. doi: 10.1523/JNEUROSCI.6488-11.2012

Kawasaki, E., Tomoda, K., Iwano, T., Kitahara, H., and Yamashita, T. (1997). "Cochlear implantation in a blind and deaf patient," in *Advances in Oto-Rhino-Laryngology*. eds. I. Honjo and H. Takahashi, vol. *52* (Basel: Karger), 89–91. doi: 10.1159/000058951

Knudsen, E. I. (2004). Sensitive periods in the development of the brain and behavior. *J. Cogn. Neurosci.* 16, 1412–1425. doi: 10.1162/0898929042304796

Kral, A. (2013). Auditory critical periods: a review from system's perspective. *Neuroscience* 247, 117–133. doi: 10.1016/j.neuroscience.2013.05.021

Kubicek, E., and Quandt, L. C. (2021). A positive relationship between sign language comprehension and mental rotation abilities. *J. Deaf Stud. Deaf Educ.* 26, 1–12. doi: 10.1093/deafed/enaa030

Kuhl, P. K. (2011). Early language learning and literacy: neuroscience implications for education. *Mind Brain Educ.* 5, 128–142. doi: 10.1111/j.1751-228X.2011.01121.x

Land, R., Baumhoff, P., Tillein, J., Lomber, S. G., Hubka, P., and Kral, A. (2016). Cross-modal plasticity in higher-order auditory cortex of congenitally deaf cats does not limit auditory responsiveness to Cochlear implants. *J. Neurosci.* 36, 6175–6185. doi: 10.1523/JNEUROSCI.0046-16.2016

Levänen, S., and Hamdorf, D. (2001). Feeling vibrations: enhanced tactile sensitivity in congenitally deaf humans. *Neurosci. Lett.* 301, 75–77. doi: 10.1016/s0304-3940(01)01597-x

Levänen, S., Jousmäki, V., and Hari, R. (1998). Vibration-induced auditory-cortex activation in a congenitally deaf adult. *Curr. Biol.* 8, 869–872. doi: 10.1016/S0960-9822(07)00348-X

Lillo-Martin, D., and Henner, J. (2021). Acquisition of sign languages. *Annu. Rev. Linguist.* 7, 395–419. doi: 10.1146/annurev-linguistics-043020-092357

Lomber, S. G., Meredith, M. A., and Kral, A. (2010). Cross-modal plasticity in specific auditory cortices underlies visual compensations in the deaf. *Nat. Neurosci.* 13, 1421–1427. doi: 10.1038/nn.2653

MacSweeney, M., Waters, D., Brammer, M. J., Woll, B., and Goswami, U. (2008). Phonological processing in deaf signers and the impact of age of first language acquisition. *NeuroImage* 40, 1369–1379. doi: 10.1016/j.neuroimage.2007.12.047

MacSweeney, M., Woll, B., Campbell, R., McGuire, P. K., David, A. S., Williams, S. C. R., et al. (2002). Neural systems underlying British sign language and audio-visual English processing in native users. *Brain J. Neurol.* 125, 1583–1593. doi: 10.1093/brain/awf153

Matchin, W., İlkbaşaran, D., Hatrak, M., Roth, A., Villwock, A., Halgren, E., et al. (2022). The cortical organization of syntactic processing is supramodal: evidence from American sign language. *J. Cogn. Neurosci.* 34, 224–235. doi: 10.1162/jocn_a_01790

Martin, E. L., Burnell, P. A., Himelick, T. E., Phillips, M. A., and Over, S. K. (1988). Speech recognition by a deafblind multichannel cochlear implant patient. *Ear Hear.* 1988, 70–74. doi: 10.1097/00003446-198804000-00004

Mathur, G., and Rathmann, C. (2012). "7. Verb agreement," in *Sign Language: An International Handbook*. eds. R. Pfau, M. Steinbach and B. Woll (Berlin, Boston: De Gruyter Mouton), 136–157.

Mayberry, R. I., Chen, J.-K., Witcher, P., and Klein, D. (2011). Age of acquisition effects on the functional organization of language in the adult brain. *Brain Lang.* 119, 16–29. doi: 10.1016/j.bandl.2011.05.007

Mayberry, R. I., and Kluender, R. (2017). Rethinking the critical period for language: New insights into an old question from American sign language. *Biling. Lang. Cogn.* 21, 1–20. doi: 10.1017/S1366728917000724

Mayberry, R. I., Lock, E., and Kazmi, H. (2002). Linguistic ability and early language exposure. *Nature* 417:38. doi: 10.1038/417038a

Merabet, L. B., and Pascual-Leone, A. (2010). Neural reorganization following sensory loss: the opportunity of change. *Nat. Rev. Neurosci.* 11, 44–52. doi: 10.1038/nrn2758

Meredith, M. A., and Lomber, S. G. (2011). Somatosensory and visual crossmodal plasticity in the anterior auditory field of early-deaf cats. *Hear. Res.* 280, 38–47. doi: 10.1016/j.heares.2011.02.004

Meredith, M. A., and Allman, B. L. (2012). Early hearing-impairment results in crossmodal reorganization of ferret core auditory cortex. *Neural Plast.* 2012, 1–13. doi: 10.1155/2012/601591

Meredith, M. A., and Allman, B. L. (2009). Subthreshold multisensory processing in cat auditory cortex. *NeuroReport* 20, 126–131. doi: 10.1097/WNR.0b013e32831d7bb6

Meredith, M. A., and Stein, B. E. (1986). Spatial factors determine the activity of multisensory neurons in cat superior colliculus. *Brain Res.* 365, 350–354. doi: 10.1016/0006-8993(86)91648-3

Mesch, J. (2001). Tactile Sign Language: Turn taking and questions in signed conversations of Deafblind People. *International Studies on Sign Language and Communication of the Deaf, 38.* Hamburg: Signum Verlag Press.

Mesch, J. (2011). Variations in tactile signing—the case of one-handed signing. Eesti ja Soome-Ugri Keeleteaduse Ajakiri. *J. Est. Finno-Ugric Linguist.* 2, 273–282. doi: 10.12697/jeful.2011.2.1.18

Mesch, J. (2013). Tactile signing with one-handed perception. *Sign Lang. Stud.* 13, 238–263. doi: 10.1353/sls.2013.0005

Mitchell, R. E., and Karchmer, M. A. (2004). Chasing the mythical ten percent: parental hearing status of deaf and hard of hearing students in the United States. *Sign Lang. Stud.* 4, 138–163. doi: 10.1353/sls.2004.0005

Moallem, T. M., Reed, C. M., and Braida, L. D. (2010). Measures of tactual detection and temporal order resolution in congenitally deaf and normal-hearing adults. *J. Acoust. Soc. Am.* 127, 3696–3709. doi: 10.1121/1.3397432

Morford, J. P. (2003). Grammatical development in adolescent first-language learners. *Linguistics* 41, 681–721. doi: 10.1515/ling.2003.022

Murray, M. M., Lewkowicz, D. J., Amedi, A., and Wallace, M. T. (2016). Multisensory processes: a balancing act across the lifespan. *Trends Neurosci.* 39, 567–579. doi: 10.1016/j.tins.2016.05.003

Nava, E., Bottari, D., Zampini, M., and Pavani, F. (2008). Visual temporal order judgment in profoundly deaf individuals. *Exp. Brain Res.* 190, 179–188. doi: 10.1007/s00221-008-1459-9

Neville, H. J., Bavelier, D., Corina, D., Rauschecker, J., Karni, A., Lalwani, A., et al. (1998). Cerebral organization for language in deaf and hearing subjects: biological constraints and effects of experience. *Proc. Natl. Acad. Sci. U. S. A.* 95, 922–929. doi: 10.1073/pnas.95.3.922

Neville, H., and Lawson, D. (1987a). Attention to central and peripheral visual space in a movement detection task: an event-related potential and behavioral study. II Congenitally deaf adults. *Brain Res.* 405, 268–283. doi: 10.1016/0006-8993(87)90296-4

Neville, H., and Lawson, D. (1987b). Attention to central and peripheral visual space in a movement detection task. III. Separate effects of auditory deprivation and acquisition of a visual language. *Brain Res.* 405, 284–294. doi: 10.1016/0006-8993(87)90297-6

Neville, H. J., Schmidt, A., and Kutas, M. (1983). Altered visual-evoked potentials in congenitally deaf adults. *Brain Res.* 266, 127–132. doi: 10.1016/0006-8993(83)91314-8

Nishimura, H., Hashikawa, K., Doi, K., Iwaki, T., Watanabe, Y., Kusuoka, H., et al. (1999). Sign language "heard" in the auditory cortex. *Nature* 397:116. doi: 10.1038/16376

Obretenova, S., Halko, M. A., Plow, E. B., Pascual-Leone, A., and Merabet, L. B. (2010). Neuroplasticity associated with tactile language communication in a deaf-blind subject. *Front. Hum. Neurosci.* 3:60. doi: 10.3389/neuro.09.060.2009

Osaki, Y., Doi, K., Takasawa, M., Noda, K., Nishimura, H., Ihara, A., et al. (2004). Cortical processing of tactile language in a postlingually deaf-blind subject. *NeuroReport* 15, 287–291. doi: 10.1097/00001756-200402090-00015

Papagno, C., Cecchetto, C., Pisoni, A., and Bolognini, N. (2016). Deaf, blind or deaf-blind: is touch enhanced? *Exp. Brain Res.* 234, 627–636. doi: 10.1007/s00221-015-4488-1

Papagno, C., Minniti, G., Mattavelli, G. C., Mantovan, L., and Cecchetto, C. (2017). Tactile short-term memory in sensory-deprived individuals. *Exp. Brain Res.* 235, 471–480. doi: 10.1007/s00221-016-4808-0

Parasnis, I., and Samar, V. J. (1985). Parafoveal attention in congenitally deaf and hearing young adults. *Brain Cogn.* 4, 313–327. doi: 10.1016/0278-2626(85)90024-7

Pavani, F., and Bottari, D. (2012). "Visual abilities in individuals with profound deafness a critical review," in *The Neural Bases of Multisensory Processes.* eds. M. M. Murray and M. T. Wallace (Boca Raton (FL): CRC Press/Taylor & Francis).

Pavani, F., and Röder, B. (2012). "Crossmodal plasticity as a consequence of sensory loss: insights from blindness and deafness," in *The New Handbook of Multisensory Processes*. ed. B. E. Stein (Cambridge: MIT Press), 737–760.

Petitto, L. A., Zatorre, R. J., Gauna, K., Nikelski, E. J., Dostie, D., and Evans, A. C. (2000). Speech-like cerebral activity in profoundly deaf people processing signed languages: implications for the neural basis of human language. *Proc. Natl. Acad. Sci. U. S. A.* 97, 13961–13966. doi: 10.1073/pnas.97.25.13961

Poizner, H., and Tallal, P. (1987). Temporal processing in deaf signers. *Brain Lang.* 30, 52–62. doi: 10.1016/0093-934X(87)90027-7

Proksch, J., and Bavelier, D. (2002). Changes in the spatial distribution of visual attention after early deafness. *J. Cogn. Neurosci.* 14, 687–701. doi: 10.1162/08989290260138591

Putzar, L., Goerendt, I., Lange, K., Rösler, F., and Röder, B. (2007). Early visual deprivation impairs multisensory interactions in humans. *Nat. Neurosci.* 10, 1243–1245. doi: 10.1038/nn1978

Quittner, A. L., Smith, L. B., Osberger, M. J., Mitchell, T. V., and Katz, D. B. (1994). The impact of audition on the development of visual attention. *Psychol. Sci.* 5, 347–353. doi: 10.1111/j.1467-9280.1994.tb00284.x

Ramsden, R. T., Boyd, P., Giles, E., Aplin, Y., and Das, V. (1993). "Cochlear implantation in the deaf blind" in *Cochlear Implants: New Perspectives*. eds. B. Fraysse and O. Deguine, Advances Oto-Rhino-Laryngology, vol. *48* (Basel: Karger), 177–181. doi: 10.1159/000422579

Reed, C. M. (1996). The implications of the Tadoma method of speechreading for spoken language processing. Proceeding of Fourth International Conference on Spoken Language Processing, Vol. 3, 1489–1492. doi:10.1109/ICSLP.1996.607898

Röder, B., Rösler, F., and Spence, C. (2004). Early vision impairs tactile perception in the blind. *Curr. Biol.* 14, 121–124. doi: 10.1016/j.cub.2003.12.054

Sandmann, P., Dillier, N., Eichele, T., Meyer, M., Kegel, A., Pascual-Marqui, R. D., et al. (2012). Visual activation of auditory cortex reflects maladaptive plasticity in cochlear implant users. *Brain* 135, 555–568. doi: 10.1093/brain/awr329

Scott, G. D., Karns, C. M., Dow, M. W., Stevens, C., and Neville, H. J. (2014). Enhanced peripheral visual processing in congenitally deaf humans is supported by multiple brain regions, including primary auditory cortex. *Front. Hum. Neurosci.* 8, 1–9. doi: 10.3389/fnhum.2014.00177

Scurry, A. N., Chifamba, K., and Jiang, F. (2020a). Electrophysiological dynamics of visual-tactile temporal order perception in early deaf adults. *Front. Neurosci.* 14:544472. doi: 10.3389/fnins.2020.544472

Scurry, A. N., Huber, E., Matera, C., and Jiang, F. (2020b). Increased right posterior STS recruitment without enhanced directional-tuning during tactile motion processing in early deaf individuals. *Front. Neurosci.* 14:864. doi: 10.3389/fnins.2020.00864

Shams, L., Kamitani, Y., and Shimojo, S. (2000). What you see is what you hear. *Nature* 408:788. doi: 10.1038/35048669

Sharma, A., Dorman, M. F., and Spahr, A. J. (2002). A sensitive period for the development of the central auditory system in children with Cochlear implants: implications for age of implantation. *Ear Hear.* 23, 532–539. doi: 10.1097/00003446-200212000-00004

Sharp, A., Landry, S. P., Maheu, M., and Champoux, F. (2018). Deafness alters the spatial mapping of touch. *PLoS One* 13:e0192993. doi: 10.1371/journal.pone .0192993

Sheedlo, H. J., and Turner, J. E. (1992). "Historical perspective on regeneration and plasticity in the visual system," in *Regeneration and Plasticity in the Mammalian Visual System*. eds. D. M. K. Lam and G. M. Bray (Cambridge, Massachusetts; London, England: Bradford Book), 3–13.

Shield, A., and Meier, R. P. (2018). Learning an embodied visual language: four imitation strategies available to sign learners. *Front. Psychol.* 9:811. doi: 10.3389/fpsyg.2018.00811

Smith, L. B., Quittner, A. L., Osberger, M. J., and Miyamoto, R. (1998). Audition and visual attention: the developmental trajectory in deaf and hearing populations. *Dev. Psychol.* 34, 840–850. doi: 10.1037/0012-1649.34.5.840

Stein, B. E., Burr, D., Constantinidis, C., Laurienti, P. J., Alex, M., et al. (2010). Semantic confusion regarding the development of multisensory integration: a practical solution. *Eur. J. Neurosci.* 31, 1713–1720. doi: 10.1111/j.1460-9568.2010.07206.x

Stein, B. E., and Stanford, T. R. (2008). Multisensory integration: current issues from the perspective of the single neuron. *Nat. Rev. Neurosci.* 9, 255–266. doi: 10.1038/nrn2331

Van Dijk, R., Kappers, A. M. L., and Postma, A. (2013a). Superior spatial touch: improved haptic orientation processing in deaf individuals. *Exp. Brain Res.* 230, 283–289. doi: 10.1007/s00221-013-3653-7

Van Dijk, R., Kappers, A. M. L., and Postma, A. (2013b). Haptic spatial configuration learning in deaf and hearing individuals. *PLoS One* 8:e61336. doi: 10.1371/journal.pone.0061336

Vernon, M. (1969). Usher's syndrome—deafness and progressive blindness: clinical cases, prevention, theory and literature survey. *J. Chronic Dis.* 22, 133–151. doi: 10.1016/0021-9681(69)90055-1

Villwock, A., Wilkinson, E., Piñar, P., and Morford, J. P. (2021). Language development in deaf bilinguals: deaf middle school students co-activate written English and American sign language during lexical processing. *Cognition* 211:104642. doi: 10.1016/j.cognition.2021.104642

Villwock, A., Bottari, D., and Röder, B. (2022). Event-related potential correlates of visuo-tactile motion processing in congenitally deaf humans. *Neuropsychologia* 170:108209. doi: 10.1016/j.neuropsychologia.2022.108209

Violentyev, A., Shimojo, S., and Shams, L. (2005). Touch-induced visual illusion. *NeuroReport* 16, 1107–1110. doi: 10.1097/00001756-200507130-00015

Weber-Fox, C. M., and Neville, H. J. (1996). Maturational constraints on functional specializations for language processing: ERP and behavioral evidence in bilingual speakers. *J. Cogn. Neurosci.* 8, 231–256. doi: 10.1162/jocn.1996.8.3.231

Welch, R. B., and Warren, D. H. (1980). Immediate perceptual response to intersensory discrepancy. *Psychol. Bull.* 88, 638–667. doi: 10.1037/0033-2909.88.3.638

Wilkinson, E., and Morford, J. P. (2020). How bilingualism contributes to healthy development in deaf children: a public health perspective. *Matern. Child Health J.* 24, 1330–1338. doi: 10.1007/s10995-020-02976-6

Willoughby, L., Manns, H., Iwasaki, S., and Bartlett, M. (2014). Misunderstanding and repair in tactile Auslan. *Sign Lang. Stud.* 14, 419–443. doi: 10.1353/sls.2014.0014

Willoughby, L., Iwasaki, S., Bartlett, M., and Manns, H. (2018). "Tactile sign languages," in *Handbook of Pragmatics 21*. eds. J.-O. Östman and J. Verschueren (Amsterdam: John Benjamins), 239–258. doi: 10.1075/hop.21.tac1

Zimmermann, M., Mostowski, P., Rutkowski, P., Tomaszewski, P., Krzysztofiak, P., Jednoróg, K., et al. (2021). The extent of task specificity for visual and tactile sequences in the auditory cortex of the deaf and hard of hearing. *J. Neurosci.* 41, 9720–9731. doi: 10.1523/JNEUROSCI.2527-20.2021

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# The socialization of modality capital in sign language ecologies: A classroom example

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Gaze behavior is an important component of children's language, cognitive, and sociocultural development. This is especially true for young deaf children acquiring a signed language—if they are not looking at the language model, they are not getting linguistic input. Deaf caregivers engage their deaf infants and toddlers using visual and tactile strategies to draw in, support, and promote their child's visual attention; we argue that these caregiver actions create a developmental niche that establishes the *visual modality capital* their child needs for successful sign language learning. But most deaf children do not have deaf signing parents (reportedly over 90%) and they will need to rely on adult signing teachers if they are to acquire a signed language at an early age. This study examines classroom interactions between a Deaf teacher, her teacher's aide, and six deaf preschoolers to document the teachers' "everyday practices" as they socialize the gaze behavior of these children. Utilizing a detailed behavioral and linguistic analysis of two video-recorded book-sharing contexts, we present data summarizing the teacher's attention-getting actions directed toward the children and the discourse-embedded cues that signal the teacher's expectations for student participation in the signed conversation. We observed that the teacher's behaviors differed according to the parent status of the deaf preschooler (Deaf parents vs. hearing parents) suggesting that Deaf children of Deaf parents arrive to the preschool classroom with well-developed self-regulation of their attention or gaze. The teachers also used more physical and explicit cueing with the deaf children of hearing parents—possibly to promote their ability to leverage the visual modality for sign language acquisition. We situate these socialization patterns within a framework that integrates notions of intuitive or indigenous practices, developmental niche, and modality capital. Implications for early childhood deaf education are also discussed.

KEYWORDS

**deaf, gaze behavior, teacher-student interaction, attention, socialization, modality capital**

## Introduction

Deaf caregivers who sign fluently actively use visual and tactile strategies to draw in, support, and promote their deaf infant's visual attention skills (e.g., Spencer et al., 1992; Swisher, 1992; Waxman and Spencer, 1997; Spencer and Harris, 2006; Pizer et al., 2011). These behaviors include physical contact and waving, adjusting interlocutor proxemics to ensure gaze connection, signing bigger and with repetition, and proto-turntaking actions. Taken together, these caregiver behaviors appear to socialize *visual modality capital*; that is, ensuring that the visual modality can be leveraged for language input. Adults who engage in these behaviors enable a deaf child to learn where to look for, and even anticipate, the source of signed linguistic information. More specifically, the child learns that (a) following their caregiver's gaze will lead to meaningful information, (b) shifting their gaze back to the caregiver after object exploration will provide linguistic information, (c) gaze shifting will enable them to follow multi-party signed conversation, (d) effective visual access means no visual obstruction should be blocking the source of linguistic information, (e) movement and visual cues (perhaps later shifting into more linguistic cues) can serve as turn taking regulators [see Horton and Singleton (2022), in this volume]. With this modality capital leveraged, a young deaf child is thus primed to acquire a language that is organized in the visual modality.

It is important to point out that modality capital can be socialized in either the auditory or visual modality. Much of the work on speech prosody, infant-directed speech patterns, speech-specific sensitivities, may be evidence for auditory modality capital in that caregiver practices can be leveraged to support spoken language acquisition (Newport et al., 1977; Grieser and Kuhl, 1988; Fernald et al., 1989). We do not assume that modality capital is acquired similarly in the auditory and visual modalities. For hearing-seeing children, the simultaneously experienced auditory (speech) and visual information presumably must be integrated to support spoken language acquisition. Auditory modality capital may be considered universal for hearing infants, even though natural variation in caregiver speech patterns occurs [see Ochs and Schieffelin (1984), Bakeman et al. (1990), Rogoff et al. (1993), and Chavajay and Rogoff (1999), for discussions of variation in caregiver speech patterns and ideologies about children and their language learning].

By contrast, deaf children are likely unable to leverage auditory modality capital for language acquisition. They will need to rely on visual information coming from multiple sources to build visual modality capital; this means they will need to learn where to look and how to integrate linguistic information from signing caregivers with objects that are visually present in the world. The extent to which deaf caregivers explicitly socialize deaf infants, creating a developmental niche (Super and Harkness, 1986, 2002) that helps them leverage visual modality capital for sign language acquisition, will be discussed in greater detail below. In her comprehensive review of the ways that social contexts support and shape language development, Hoff (2006) does not consider how language modality factors into the ecology where language acquisition takes place. We maintain that the human solution of leveraging visual modality capital for sign language acquisition may also be a "reliable result of the mental processes set in motion when the child meets the social and linguistic world" (Hoff, 2006, p. 78).

## Importance of attention and gaze

Joint attention, where an adult and infant jointly attend to the same object, is viewed by many developmental researchers to be a key psychological process and is argued to be critical for developing basic socio-cognitive understanding and language in the auditory modality (Tomasello and Farrar, 1986; Bornstein, 1990; Adamson and Bakeman, 1991; Baldwin, 1995; Tomasello, 1995, 1999; Carpenter et al., 1998; Brooks and Meltzoff, 2002, 2005, 2008; Mundy, 2003). An infant first "learns to" gaze-follow and then "learns from" gaze-following as the social-cognitive component becomes better established (Vaughan van Hecke and Mundy, 2007, p. 40). The capacity to self-regulate one's own visual attention also serves as one of the earliest components of the Executive Functions to come "online" (Anderson, 2002). According to Posner and Rothbart (2000, 2007), there are three stages of orienting attention. First, an individual must disengage from what they are presently looking at, then they must shift their attention to the new location, and finally they engage their attention to the new target. While there are early developing capacities in self-regulation of attention around ages 9–12 months (Ruff and Rothbart, 1996), the period between 12 and 36 months marks a significant advance in the child's self-regulatory abilities (Bronson, 2000). Researchers have described both exogenous (e.g., a caregiver's voice, a loud noise, or a flashing light) and endogenous factors (e.g., self-interest in a toy) that contribute to the process of orienting our attention. It is important to recognize that a child's developing capacity to engage in mutual and joint attention, insofar as they integrate what they see and what they hear, is shaped by both maturation and environmental/interactional processes (Rothbart et al., 1990; Ruff and Rothbart, 1996; Mundy and Sheinkopf, 1998; Posner and Rothbart, 2000).

Studies involving hearing children have shown that eye gaze serves as an important window into cognitive functioning. For example, children who are later diagnosed with autism spectrum disorder are found as young children to exhibit gaze behaviors that differ from neurotypical children (Dawson et al., 1998; Baron-Cohen, 2000; Mundy et al., 2000; Adamson et al., 2009; Klin et al., 2009). Children with Down Syndrome are slower to hit developmental milestones in gaze following (Adamson et al., 2009). Children with Attention Deficit Disorder also show atypical patterns of development of attention/gaze [see Ruff and Rothbart (1996), for review]. In typically developing children under the age of one, the capacity to follow an adult's shift in gaze appears to be a significant correlate of early spoken language vocabulary acquisition (Mundy et al., 1995; Carpenter et al., 1998; Morales et al., 2000; Meltzoff and Brooks, 2008). Lastly, gaze behavior and proxemics can also vary or be influenced by local gaze norms used by hearing individuals within different cultural communities (Chavajay and Rogoff, 1999; Gaskins and Paradise, 2010; de León, 2011; Haviland, 2020; Horton et al., under review[1]).

In this study, we examine the *socialization of gaze behavior* among deaf children. We first explore how deaf caregivers establish linguistic and modality-based practices to promote their children's development of attention and successful visual language acquisition. We then investigate how deaf teachers take on this same task within the context of their preschool classroom.

## Theoretical framework for socializing gaze and attention

As we explore further how adults socialize deaf children's attention and gaze behavior, we shall first outline some theoretical orientations that frame our interpretation of this developmental process. First, we look at the social engagement behaviors initiated by adults and directed toward children as part of a larger system of parenting beliefs and practices, communication, and socio-cultural interaction patterns within a community. Caregivers possess certain indigenous knowledge systems or intuitive parenting practices (Papoušek and Papoušek, 1987), use culturally relevant artifacts, and hold certain beliefs about children's capacities, all of which form what Super and Harkness (1986, 2002) call a "developmental niche." Within this niche, caregivers guide their children, scaffolding their behaviors, and support their development as full participants in their family and community (Rogoff, 1990, 2003; Rogoff et al., 1993; Chavajay and Rogoff, 1999).

Beyond the social interaction perspective, we also situate gaze behavior within a developmental and dynamic cognitive system (Corina and Singleton, 2009). Control of one's attention allocation is part of a larger cognitive system regulated by the executive functions of the brain. Self-regulation requires both active attending as well as inhibition (i.e., suppressing one's interest in an attractive object in response to a caregiver's bid for attention). As a child builds capacities in basic attention regulation, one sees growth in more "higher order" cognitive processes such as working memory, planning, and cognitive flexibility (Ruff and Rothbart, 1996). It is important to note that all children, hearing or deaf, are visually oriented and develop gaze-following behavior that is eventually self-regulated. What is unique about being raised in deaf, sign language-using families, is that attracting, maintaining, and directing an infant's visual attention is essential for visual language communication to take place. The literature on deaf caregivers' visual engagement patterns suggests strongly that their young children are being socialized to attend in unique ways. Deaf caregivers often create a developmental niche that appears to capitalize upon the visual modality and results in the shaping of an infant's attentional capacities. We argue that they are intuitively building "modality capital," through which caregiver-child interactions—replete with attention-shifting and linguistic demands—become a synchronous and natural experience.

## Socialization of deaf children's visual modality capital

The social and communicative interactions between Deaf caregivers and their deaf children have been studied across many cultural contexts [see Spencer and Harris (2006), for a review] including the United States (Erting et al., 1990/1994; Spencer et al., 1992; Swisher, 1992; Waxman and Spencer, 1997; Koester et al., 1998; Lieberman et al., 2011, 2014; Pizer et al., 2011), Canada (Jamieson, 1994), the United Kingdom (Harris et al., 1989; Ackerman et al., 1990; Smith and Sutton-Spence, 2005; Guarinello et al., 2006), Australia (Mohay et al., 1998), Belgium (Loots and Devise, 2003; Loots et al., 2005), and Japan (Masataka, 1992). Many deaf caregivers scaffold visual modality capital by engaging their young children in particular ways that attract and maintain their visual attention ensuring that the child is able to see the signed language input the caregiver provides. Some examples of this visual "attunement" include producing signs within child's visual field, pausing their signing until the infant is looking, moving objects closer to the caregiver's face, using more exaggerated facial expressions, imparting rhythmicity in a sign's movement, and use of visual attention-getting behaviors like waving at or tapping the child (Pizer et al., 2011). Some caregivers also use tactile, vocal, and kinesthetic stimulation (Harris et al., 1989; Koester et al., 1998, 2004). Deaf caregivers also appear to use shorter phrases and repetition in their signing (Spencer and Harris, 2006). This strategy enables them to capitalize on the potentially brief window of opportunity of mutual connected eye gaze and provides multiple opportunities for the child to make associations between the visual referent and the signed form. Many of these caregiver behaviors decrease over time as the infant increases their self-regulation of attention (vis-à-vis accrued modality capital) as well as understands that the tapping or waving signal means "look to the caregiver" for language. Eventually, the child will anticipate the appropriate time to look-to-caregiver, relying upon linguistic devices and turn-taking cues present in the discourse, rather than being physically tapped by the caregiver.

1 Horton, L., Hou, L., German, A., and Singleton, J. (under review). *Sign Language Socialization and Participant Frameworks in Three Indigenous Mesoamerican Communities*.

From the perspective of the child, we know that deaf infants born to deaf (DoD) families show early control over gaze following and gaze-shifting compared to non-signing hearing infants (Brooks et al., 2019). Lieberman et al. (2014) investigated Deaf mothers and their children engaging in book-sharing activities. They observed that even by the age of 2, the DoD toddlers more frequently shifted their eye gaze back and forth between the caregiver and the book as compared to deaf children of hearing parents. We also know that compared to deaf children of hearing parents (DoH), DoD engage in more spontaneous looking to their caregiver (which requires inhibiting one's attention from an interesting object and shifting one's gaze to the caregiver) (Harris and Mohay, 1997). This is not to say that hearing caregivers do not engage in modality capital promoting behaviors with their deaf child, but the primary finding from accumulated observational research is that there is more variability in hearing parents' attention-getting strategy use, greater asynchrony in their timing of sign production, and their "bouts" of joint attention with their deaf child are shorter, thereby leaving a narrower window of language learning opportunity (Spencer and Harris, 2006). Furthermore, Prezbindowski et al. (1998) contend that deaf children of hearing caregivers exhibit atypicality in their regulation of attention "…long before they exhibit noticeable language delays" (386).

To summarize, research on caregiver–child interaction in infancy and toddlerhood suggests that deaf children born to deaf families are being socialized into a visual language community through a set of everyday caregiver behaviors that ensure the child will develop visual modality capital. For deaf children born to hearing parents (reportedly over 90% of the deaf population, Holcomb, 2013), however, the early childhood education classroom, possibly with a deaf signing teacher, may be the first "caregiver-like" context in which they are exposed to the kinds of systematic socialization of visual modality capital that has been so well-documented in deaf–deaf family dyads (Singleton and Morgan, 2006; Singleton and Meier, 2021). Moreover, expectations for the child's classroom behavior (e.g., sitting still in a preschool class) will also require the child to increase in inhibitory control, sustained attention, and shifts in attention (Ruff and Rothbart, 1996).

## Teachers as socializing agents of visual modality capital

There are a few classroom studies where teachers' use of visually based socialization practices with deaf students is documented. For example, Mather (1987) found that in teacher-led group interaction, signing teachers use three types of eye gaze signals to convey information about their intended addressee. *Group-indicating* gaze employs a "smooth arc-like" glance toward the group and indicates that the teacher's question or comment is intended for all group members. Similarly, *audience gaze* conveys that the entire group is the intended addressee, but in this case, a teacher selects a midpoint of the group to affix her gaze, rather than the swoop of the group-indicating gaze. *Individual gaze* is directed at one child and conveys to other members of the group that it is not their turn; instead, that the floor is to be held by the specific addressee. In sum, students in signing classrooms may use the teacher's eye gaze cues to learn when they are being addressed and whether it is appropriate to make a bid for the teacher's attention.

Eye gaze signals convey important discourse cues to the conversational partner. Mather and Thibeault (2000) explain that signers use gaze, along with the creation of a "surrogate" signing space and head/shoulder tilts, to convey "constructed dialogue." Such embodied "role shifts" tell the other signer that you are not speaking directly to them, but rather you are becoming another character, similar to "reporting speech." This way the addressee understands that the storyteller is no longer in narrator mode but is constructing the dialogue in the story. Hearing children can rely upon auditory cues such as changes in voice quality and other paralinguistic features to identify which character the narrator has become. In contrast, deaf children rely upon the eye gaze behavior and body posture of the storyteller to follow the discourse shifts (Mather and Thibeault, 2000).

To investigate the visual engagement patterns of a deaf teacher interacting with deaf ($n$ = 2) and hearing ($n$ = 2) preschoolers as they engaged in different play contexts (play dough and dramatic play), DeLuzio and Girolametto (2006) adapted Koester et al.'s (1998) coding system for documenting caregiver's attention-eliciting behaviors. While no differences across play contexts were found, the deaf educator relied heavily upon tactile and visual attention-getting strategies with her 3- and 4-year-old students. The authors suggest that the educator may also have responded differently to the hearing status of the child, but they did not provide corresponding data broken down with respect to this issue.

Smith and Ramsey (2004) looked at older deaf students in fifth grade and analyzed their classroom interactions with a deaf teacher. While the focus of this study was more on instructional conversation discourse features, there were some documented patterns of gaze, non-manual markers, and discourse-embedded cues that were deployed by the teacher to control conversation flow. The teacher was also persistent in her attempts to get deaf students engaged and frequently checked their comprehension (often through a subtle non-manual marker). Smith and Ramsey also noted that the students in the class used hand-raising and hand-waving to gain the teacher's attention (54).

Departing from a focus on the actions of deaf teachers, Lieberman (2015) documented the attention-getting actions produced by seven deaf native ASL signing toddlers during their classroom interactions with deaf peers and their teachers. Briefly, Lieberman shows compelling evidence that young deaf toddlers are already capable of using attention-getting strategies in their signed interactions with their classmates. We will pick up again on Lieberman's analysis in the Section "Discussion."

In sum, a young deaf child immersed in a visual language ecology (i.e., a developmental niche) learns to rely on sophisticated and complex eye gaze signals in order to leverage the visual modality and gain access to linguistic input (signed language) and acquire the social interaction norms for visual language exchanges. Apart from the aforementioned studies, the research literature has not documented classroom interaction processes to a level that will help us understand better "what works" in deaf educational settings and how particular instructional strategies may be more effective than others in building deaf children's visual modality capital.

## Materials and methods

For this study, we conducted a detailed naturalistic observation of deaf teachers in early childhood deaf education classrooms, across two different interaction contexts, to document the kinds of teacher practices that were used to gain and direct deaf preschooler's visual attention. By examining the type of teacher strategy, as well as to whom (Deaf child of Deaf parents, or deaf child of hearing parents) a particular strategy was directed, we could document teacher's behaviors that appear to socialize a deaf child's visual modality capital.

### Participants

The study includes one teacher and one teacher's aide, both deaf and highly fluent in American Sign Language (ASL). The teacher was nominated for the study by the principal of the residential school for the deaf for being an outstanding ASL language model at the preschool level. All six children in this selected preschool classroom have profound or severe-to-profound hearing loss (see Table 1). Child 1 (male, age 4;8), Child 4 (male, age 4;6), and Child 6 (male, age 5;0) had Deaf ASL-using parents. The teacher reported to us that all of these Deaf parents are fluent in ASL based on her firsthand experience interacting with them. Child 2 (female, age 5;5), Child 3 (male, age 5;8), and Child 5 (female, age 5;10) had hearing parents or guardians, whom the teacher reported has minimal ASL signing skills. While we recognize that parent hearing status is not always a proxy for ASL fluency, in the specific case of this study, we felt comfortable using the DoD and DoH terminology to reflect these children's early signing experience and their potential level of ASL fluency. We note that the three DoD were on average, younger than the three DoH children in this Pre-K classroom. Child 3 (DoH) has a cochlear implant on the right side that was not in use at the time of the study. Child 5 (DoH) had only been in the classroom for a few weeks, while the other students had been enrolled at least since the start of the school year in this program, which was a few months before our observation.

TABLE 1 Child characteristics.

| Child | Gender | Age | Hearing status | | Ethnicity |
|---|---|---|---|---|---|
| | | | Child's | Parents' | |
| 1 | Male | 4;8 | Profound | Deaf | White |
| 2 | Female | 5;5 | Severe to profound | Hearing | White |
| 3 | Male | 5;8 | Profound | Hearing | White |
| 4 | Male | 4;6 | Severe to profound | Deaf | White |
| 5 | Female | 5;10 | Profound | Hearing | Black |
| 6 | Male | 5;0 | Profound | Deaf | White |

### Context: Bilingual American Sign Language/English preschool for deaf children

To examine these socializing practices, we analyzed video-recorded data that captured natural interactions in preschool classrooms between deaf teachers and deaf children who are 4-to-5 years old. The selected preschool is part of a residential school for deaf children adopting a bilingual, bicultural approach to communication. The school uses two languages for communication: ASL and English (primarily through the written form, although some students also receive some spoken English instruction during the day). The data for this study are drawn from a larger collection (18 h) of video-recordings from multiple preschool and nursery school classrooms with deaf teachers at this site. The classroom interactions were recorded using a single video camera on a portable tripod during six visits over one semester. Different activities were recorded including group-based and individual activities involving several Deaf teachers. The video-recordings were collected by one co-author (Singleton, a hearing native ASL signer) and another investigator (a hearing, second language learner of ASL with very high fluency) after several observational visits without a camera so that the children would get used to their presence as observers. The second co-author (Crume, a hearing native ASL signer) joined the project at the coding and data analysis stage. The teachers were told that we were generally interested in classrooms where ASL is the language of instruction and that they should go about their normal routines. From the video-recordings, it is evident that the teachers and children went about their everyday classroom business; in the case of the selected episodes, the children and teachers were clearly used to the camera and researchers' presence and did not look at the researchers during the episode.

### Episode selection

For the purpose of this study, we wanted to use two episodes of teacher-led group book-sharing sessions, from the same teacher. From the larger archive, we identified two episodes that met the following criteria: similar in length, had the same six students in attendance, and used the same book during the sharing activity. We targeted teacher-centered book-sharing sessions because these contexts require a high level of visual engagement and attention management (both teacher-directing and student self-regulating). In these episodes, the teacher is typically seated on the floor with the six children seated facing her in a semi-circle. The teacher must gain and maintain the children's attention and the children must rapidly shift their gaze to other children as children take turns "holding the floor." Additionally, the teacher directs children's attention to a particular child, a book, or other visual media (such as a calendar). The children also vie for the teacher's attention when attempting to bid for the floor.

The first selected episode is just over 20 min in length, and the second is closer to 16 min. In the first episode, the teacher introduces students to a particular storybook for the first time. In this activity, the teacher did not read the book verbatim, but instead lets students examine each page and offer their own comments about the story ("a picture walk"). There is minimal structure in this activity and students were free to respond when they had ideas to share. In the second episode, video-recorded 2 weeks later, the same teacher engages the same six children in a dramatic "roleplay" retelling of the same storybook used in the earlier picture walk episode. In this activity, the teacher assumes the role of the main character in the book and each student plays a specific animal character found in the story. The students appear familiar with the story because of prior teacher readings before this point in the data collection; they know the content of the book and their responses follow the actions their animal characters experienced in the story. This second episode also includes a deaf teacher's aide seated on the floor just behind the semi-circle of students. We did not obtain information from the principal about the signing skills of the deaf Teacher's Aide. Our informal impression based on reviewing video-recordings in the full archive is that she is a fluent signer of ASL.

The storybook, *Ask Mr. Bear* (Flack, 1932), was used in both video-recorded book-sharing activities. The book is about a boy who goes out looking for a birthday present for his mother. In his search, the boy meets different animals and asks them if they have anything to offer as a potential present (e.g., feathers, wool, milk, cream). As he meets each animal, the boy finds that he already possesses what each animal has to offer until he meets Mr. Bear who suggests that he give his mother a bear hug.

## Context for episode 1 (picture walk)

In the first group activity, the picture walk, the teacher tries to connect the animal characters in the book with the students' own experiences with animals. She opens the activity by discussing what students saw at a previous class field trip to the zoo. The teacher asks each student to recount his or her experience on the zoo trip, rapidly moving from one student to the next. In the middle of this sequence, the teacher stops at one student because she remembered that he did not go on the zoo field trip because he had his tonsils removed. The teacher uses this opportunity to discuss further the student's experience being hospitalized, while encouraging the rest of the students to watch the conversation. After this sidebar with the zoo-absent student, the teacher resumes asking the other students about zoo animals. She subsequently asks the children to predict what animals they might see at an upcoming field trip to a farm. After the question and response activity about the farm animals, the teacher introduces the *Ask Mr. Bear* book to the students and explains that she wants their input about the story. However, the students are quite distracted, and it takes her a considerable amount of time to settle them down and focus on the main part of the book-sharing activity. After the teacher gains the students' attention, she begins the picture walk activity. She subsequently shows the students each page, pointing to specific features in the illustrations, and asks students to share their thoughts. In the middle of the activity, a few students lose focus and begin to play and disregard the book-sharing activity. The teacher regains the attention of these students and encourages them to focus again on the picture walk activity. Once the students are resettled, she continues the picture walk until its completion. Table 2 provides an event breakdown and description of the picture walk book-sharing activity.

## Context for episode 2 (role play)

The second group activity, the role play, occurred 2 weeks later. In the role play, the teacher displays a tray of props that includes a paper cut-out picture of each animal that appears in the book, an index card with character's name, and a specific item relevant to each animal (e.g., wool for the sheep, feathers for the duck). The role play activity is obviously familiar to the

TABLE 2 Periods within episode 1–picture walk (total time: 21:33).

| Period | Minutes | Description |
|---|---|---|
| Introduction | 3:55 | The teacher connects a previous zoo fieldtrip and an upcoming trip to a farm to prepare them for the Ask Mr. Bear book, which features several animals |
| Sidebar | 2:01 | The teacher interrupts her introduction to engage in a sidebar conversation with a student about his experience getting a tonsillectomy and uses this as a teachable moment for the class |
| Transition | 1:43 | The teacher prepares the students for the book sharing activity by providing instructions of the "Picture Walk" activity |
| Main activity (picture walk) | 13:01 | Students describe what they think is happening on each page of the book. The teacher scaffolds students' learning by elaborating upon their responses |
| Refocus | 0:53 | During the middle of Picture Walk, the students become somewhat disengaged and the teacher redirects their attention back to the book |

students. The teacher begins the activity by stating it [the story] was the same as the other day. Immediately, several students get up from their sitting position in the semi-circle and crawl over to the prop tray and begin to grab props for a character they want. The teacher and aide have to get the attention of several students, encourage them to sit down, and assure them that they will each have their opportunity to select a character. Once the students are settled, the teacher asks each student which character they prefer and distributes the corresponding prop from the tray to each student. She then initiates the dramatic role play story retelling of *Ask Mr. Bear*. In the role play, the teacher assumes the main character role of the boy in the story and then engages each student as his/her specific character in the order they appear in the book. An event breakdown of the role play activity is detailed in **Table 3**.

## Coding procedure

Our coding procedure is an integration and modification of coding systems used by three different research groups in their analysis of classroom interactions involving deaf students (Mather, 1987, 1989; Mather and Thibeault, 2000; Smith and Ramsey, 2004; DeLuzio and Girolametto, 2006). Mather and colleague (Mather, 1987, 1989; Mather and Thibeault, 2000) analyzed preschool classroom interactions with deaf students and teachers and classified whether the teachers' gaze was directed toward the entire group or toward an individual student. DeLuzio and Girolametto (2006) analyzed how teachers used visual and tactile strategies to gain or regain students' attention in structured and unstructured educational contexts. Finally, Smith and Ramsey (2004) investigated classroom discourse practices, for example speaker roles and devices that maintain discourse coherence. Our adaptation combines and extends these authors' research by including a range of attention-getting and attention-directing behaviors produced by the teachers, as well as how they manage the participation roles of the children in both structured and unstructured discourse settings. These specific actions are further detailed in the next section.

TABLE 3 Periods within episode 2 (role play) (total time: 15:40).

| Period | Minutes | Description |
|---|---|---|
| Introduction | 1:55 | The teacher and aide work to get the students settled and explain the upcoming activity |
| Distribution | 3:40 | The teacher distributes the props that the students will use during the storybook activity |
| Transition | 0:45 | The teacher and aide work to settle the children and begin the storybook activity |
| Main activity (roleplay) | 9:20 | The teacher tells the story by taking on the role of the main character while the students respond according to their assigned character in the book. The book text is not "signed aloud" word by word |

The coding of teacher's language and actions was completed by both co-authors, who are both hearing, native ASL signers. As one independent measure of the co-authors' ASL skills, both have earned national certification as sign language interpreters and possess many years of experience engaged in sign language-related research. Each co-author independently coded 25% of the other co-author's coding to ensure coding accuracy. The very few coding discrepancies that occurred were resolved through discussion and resolution.

To be clear, the students' attention actions (e.g., direction of eye gaze) are not directly analyzed in this coding scheme because, with the limitations of a single camera view that was trained primarily on the teacher (with the semi-circle of students in view), we could not reliably record the student's gaze behaviors.

### Attention actions and participation cues of the teacher

The teacher's production of *Attention Actions* and *Participation Cues* emphasize different aspects of the socialization of children's visual engagement (i.e., visual modality capital). Attention actions represent behaviors used by the adult to direct the eye gaze of the students, either toward the adult requesting the attention (i.e., toward self) or to another target, such as another adult, classmate, or resource. Participation cues represent the kind of scaffolding an adult produces within discourse that serves to maintain discourse cohesion (e.g., NOW, OK) but also implicitly conveys that "you should be looking at me"; also, these cues inform or shape the child's behaviors with respect to appropriate participation in a visual language-using group interaction (e.g., WAIT, HOLD, YOUR-TURN). For example, in our observations, adults use participation cues to support students' development of appropriate timing for turn-taking and cues about positioning themselves for successful visual engagement (e.g., sitting upright and ensuring no obstacles or people are obstructing the child's view of the signer).

Attention actions produced by the teacher and aide are further divided into two types: *Attention-Gaining* actions and *Attention-Directing* actions. Attention-Gaining (AG) actions serve to attract the gaze of students toward the teacher. Attention-Directing (AD) actions attempt to re-direct the attention of a student to another adult, peer, or target object. Both types of attention actions include the same three categories of prompts used by the adult: linguistic, physical, and non-manual. Linguistic prompts are single signs or short phrases such as HEY! (hand-wave), PAY-ATTENTION, LOOK-AT-ME, LOOK-AT-HIM. These signs are produced within the visual field of the student(s). Physical prompts are light touches or taps on the child's body (e.g., shoulder, arm, leg) or physical actions on an object (e.g., shaking an object to attract the child's attention). Non-manual prompts are actions that include only the use of facial expressions or head/body behavior (e.g., tilting head) to draw the child's attention toward the adult or another person (there is no co-occurring sign with the non-manual prompt). While it is not discussed specifically here, many of the linguistic prompts did co-occur with animated facial expression—this would be expected in the child-directed register that is being used by the teacher. Each AG and AD action is counted; for repeated signs (e.g., LOOK, LOOK, LOOK) each token is counted individually. A list of examples is provided in **Table 4**.

Participation cues are defined as an adult conveying to students, through their discourse, the expected norms for how to participate in the visual language conversation (see **Table 4**). As Smith and Ramsey (2004) documented in a fifth-grade classroom of deaf students, the deaf teacher invites students to participate in the teacher-directed group interaction, using signs like "NOW" or "OK," conveying that it is time to be quiet and pay attention. In this classroom of deaf students, the teacher establishes individual gaze and/or point, nod, or uses a non-manual marker to a child to yield them the speaker's role (Mather, 1987; Smith and Ramsey, 2004). Sometimes her hand will remain pointing to help other children "find" the child who now has the floor. This placeholder also conveys that other children should not interrupt. The children can also anticipate their upcoming turn when the teacher invites them with a sign like YOU-NEXT!

Successful participation in a visual language conversation also requires optimizing visual sightlines, ensuring that no obstacles or persons are obstructing their view of the teacher's signing. For example, the teacher may issue a directive telling a child to alter their undesirable position, by signing phrases such as MOVE-BACK, MOVE-FORWARD, SIT-UP, and asking SEE CLEAR?

Participation cues also include teacher behaviors that have the effect of delaying or refusing a child's bid for participation. For example, when a child tries to interrupt the teacher or another child who is signing (i.e., they hold the floor in the group conversation), the teacher tries to *delay* the child's participation, by using signs like WAIT (index finger held up), HOLD, WILL++ (e.g., you will have your turn). Sometimes, when a child persistently tries to get the teacher's attention (when the teacher is attending to another child), even after they have been asked to wait, the teacher will *refuse* their bid by purposely not looking at them or even pushing their "waving hand" down.

## Results

The purpose of this study is to examine the ways in which deaf teachers socialize deaf preschoolers into full participation in a visual language ecology. Our detailed classroom observations focus on one deaf teacher, and one deaf teacher's aide, as they interact with six deaf preschoolers in two separate teacher-directed group instruction settings. The first episode, the

TABLE 4 Coding category descriptions: Teacher's visual engagement actions.

| Type | Category | Description | Examples of signs or behaviors |
|---|---|---|---|
| Attention-gaining | Linguistic prompt | Single signs or short phrases used within the visual field of student(s) | PAY-ATTENTION; LOOK-AT-ME; HEY! (Hand-wave); Calling child's name (with namesign or fingerspelling) |
| | Physical prompt | Light tap or touch on the child when he/she is not attending to the teacher | Tapping, Nudging, Holding different part of body |
| | Non-manual prompt | Use of non-manual markers (without accompanying sign) in the visual field of the child | Facial expressions (e.g., raised eyebrows for "Well?" or pursed lips for "I'm waiting"); shoulder shrugs |
| Attention-directing | Linguistic prompt | Signs or short phrases used within the visual field of the student(s) in order to direct attention toward a person or object. | LOOK-AT-THIS (teacher-student-object); LOOK-AT-HIM/HER; re-directing point |
| | Physical prompt | Enhancing visual interest of the object to direct child's attention toward it | Shaking an object (e.g., raising a book up and down) to attract the child's attention to it. |
| | Non-manual prompt | Use of non-manual markers (without accompanying sign) in the visual field of the child | Head tilt and eye glances to direct child's attention toward another person or object |
| Participation cues | Invite | Action or a statement that signals to student(s) that they should be attending, and may be encouraged to make a statement or ask a question | READY?; NEXT; a point to the person (finger or arm point), a head nod |
| | Directive | Authoritative comment with the intention of monitoring or altering the child's undesirable (e.g., visually obstructed) position, behavior, or action | MOVE-FORWARD, MOVE-BACK, SIT-UP, SEE-CLEAR? |
| | Delay | Comment intended to get students to wait or postpone a specific request or comment | WAIT, WILL++, HOLD |
| | Refusal | Action produced in response to a child who is inappropriately bidding for the teacher's attention. The teacher does not yield her attention to this interruption. | Not giving eye contact to a student who is bidding for attention; pushing down or holding the child's hand |

"Picture-Walk" (21 m, 33 s), is considered less-structured and the preschoolers are allowed to freely participate in the communication interaction as they sit in a semi-circle facing the teacher who is "walking them through" a children's picture book without explicitly reading it to them. The second episode, the "Role Play" (15 m, 40 s), is more structured than the first activity as each student is provided with an explicit participation turn (role play) in the story-retelling. Turn-taking in this activity is regulated by the teacher. This observation also involves a deaf teacher's aide who is sitting behind the children in the semi-circle facing the teacher.

Our analysis for this study focuses on the attention actions and participation cues produced by both the teacher and the teacher's aide. We count the number of prompts geared toward the whole group (as indicated by what Mather terms *group-directed gaze or audience gaze)* or toward individual students (*individual-directed gaze)*. These individual prompts are also divided according to whether they are directed toward Deaf children of Deaf parents (DoD), or deaf children of hearing parents (DoH). We are especially interested in whether the patterns of teacher behavior differ when they are directed toward DoD as compared to DoH. This comparison is of particular interest as we expect that DoD preschoolers at this age would already possess visual modality capital because of their experience in the home environment of being socialized early into a visual language ecology. Thus, we predict that DoD will less often be the target of attention-gaining or directing actions from the teacher compared to DoH students who are presumably entering the classroom (i.e., this developmental niche) with less prior visual language experience (i.e., less modality capital).

## Attention-gaining actions

The teacher uses Attention-Gaining actions to elicit the students' attention either through linguistic prompts (e.g., handwaves, LOOK-AT-ME), physical prompts (e.g., light touches on the body), or non-manual prompts (e.g., raised eyebrows). Overall, we document a total of 187 Attention-Gaining (AG) prompts that the teacher directs to students in Episodes 1 and 2 combined. Of the 187 AG prompts, 109 (58%) are directed toward students who have hearing parents (DoH), 65 (35%) are directed toward students with deaf parents (DoD), and 13 prompts (7%) are directed toward the class as a whole. These results are summarized in **Table 5**.

The overall results indicate similarities and differences in the types of Attention Gaining prompts geared toward the DoH

TABLE 5 Teacher and teacher aide attention gaining actions in the unstructured picture walk (21:33) and structured role play (15:40) episodes.

| Attention gaining | Tokens | | | Frequency | | |
|---|---|---|---|---|---|---|
| | Group | DoD | DoH | Group | DoD | DoH |
| **Teacher (unstructured)** | | | | | | |
| Linguistic prompt | 3 | 26 | 20 | 0.06 | 0.53 | 0.41 |
| Physical prompt | 1 | 12 | 31 | 0.02 | 0.27 | 0.70 |
| Non-manual prompt | 2 | 0 | 1 | 0.67 | 0.00 | 0.33 |
| Total | 6 | 38 | 52 | 0.06 | 0.40 | 0.54 |
| **Teacher (structured)** | | | | | | |
| Linguistic prompt | 4 | 7 | 12 | 0.17 | 0.30 | 0.52 |
| Physical prompt | 2 | 16 | 8 | 0.03 | 0.62 | 0.31 |
| Non-manual prompt | 1 | 2 | 2 | 0.20 | 0.40 | 0.40 |
| Total | 7 | 25 | 22 | 0.13 | 0.46 | 0.41 |
| **Teacher aide (structured)** | | | | | | |
| Linguistic prompt | 0 | 2 | 3 | 0.00 | 0.40 | 0.60 |
| Physical prompt | 0 | 0 | 32 | 0.00 | 0.00 | 1.00 |
| Non-manual prompt | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 |
| Total | 0 | 2 | 35 | 0.00 | 0.05 | 0.95 |
| Overall total | 13 | 65 | 109 | 0.07 | 0.35 | 0.58 |

TABLE 6 Teacher and teacher aide attention directing actions in the unstructured picture walk (21:33) and structured role play (15:40) episodes.

| Attention directing | Tokens | | | Frequency | | |
|---|---|---|---|---|---|---|
| | Group | DoD | DoH | Group | DoD | DoH |
| **Teacher (unstructured)** | | | | | | |
| Linguistic prompt | 0 | 3 | 4 | 0.00 | 0.43 | 0.57 |
| Physical prompt | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 |
| Non-manual prompt | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 |
| Total | 0 | 3 | 4 | 0.00 | 0.43 | 0.57 |
| **Teacher (structured)** | | | | | | |
| Linguistic prompt | 0 | 1 | 2 | 0.00 | 0.33 | 0.67 |
| Physical prompt | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 |
| Non-manual prompt | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 |
| Total | 0 | 1 | 2 | 0.00 | 0.33 | 0.67 |
| **Teacher aide (structured)** | | | | | | |
| Linguistic prompt | 1 | 1 | 30 | 0.03 | 0.03 | 0.94 |
| Physical prompt | 0 | 0 | 1 | 0.00 | 0.00 | 1.00 |
| Non-manual prompt | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 |
| Total | 1 | 1 | 31 | 0.03 | 0.03 | 0.94 |
| Overall total | 1 | 5 | 37 | 0.02 | 0.12 | 0.86 |

and DoD students. The two groups of students receive the same number of linguistic prompts ($n$ = 35) and a similar number of non-manual prompts ($n$ = 6 and $n$ = 4, respectively) directed toward them. While the non-manual prompts are used sparingly as an isolated directive (e.g., raised eyebrows), this nevertheless appears to be a subtle tool used to gain the student's attention.

In contrast, the DoH students receive far more physical prompts (71 out of 102) from the teacher than do the DoD students (28 out of 102) even though the distance to reach any student is essentially equal as they are positioned in a semi-circle in front of her. This difference is illustrated by the fact that the teachers often resort to a physical touch to get the attention of the DoH students, especially if they are unable to get their attention through the discourse-embedded strategies of linguistic or non-manual prompts.

In comparing the two episodes, when the teacher's aide is present (in the Structured activity), the teacher lessens her use of the physical prompts, seemingly relegating that responsibility to the aide (Note: we observed on the video the teacher asking the aide to sit near the three DoH students to "help manage them"). Specifically, in the Picture Walk (Episode 1), the teacher directs more physical prompts toward the DoH students ($n$ = 31) than the DoD students ($n$ = 12). In the Role Play (Episode 2), the teacher and aide combined direct 40 physical prompts toward the DoH students compared to only 16 toward the DoD.

## Attention-directing actions

The teachers appear to use the Attention-Directing (AD) actions to help students focus their attention on the primary person (e.g., teacher or student) or object of interest. As summarized in Table 6, of the 43 AD actions documented in both episodes, by both teacher and aide, 42 are linguistic prompts (e.g., LOOK-there) and one prompt is physical (the aide touches an object that a student was holding). This makes sense because (as was reported to us by several deaf teachers) within Deaf Culture one would not normally rely upon a physical prompt to redirect the child's attention (i.e., it would be rude to place one's hand on a person's head and forcibly turn it toward the new target). In total, 86% of the AD actions produced by the teachers are directed toward the DoH students ($n$ = 37), while the DoD receive only 12% ($n$ = 5). Only one linguistic AD prompt (2%) is directed toward the class as a whole. Due to the nature of the activity, the teacher uses the Attention Direct prompts sparingly, as she is focused mostly on gaining their attention (to herself) and eliciting information from the students. By comparison, as is appropriate for her role, the teacher's aide makes far greater use of the Attention Direct prompts (e.g., LOOK-AT TEACHER!) to scaffold the direction of the DoH students' gaze.

Figure 1 illustrates the combined pattern of results presented in Tables 5, 6.

## Participation cues

The participation cues are divided into types of cues that appear to encourage students' positive participation like READY? or YOU-NEXT! (Invite) with those that discourage negative behaviors such as interruptions (Directive, Delay,

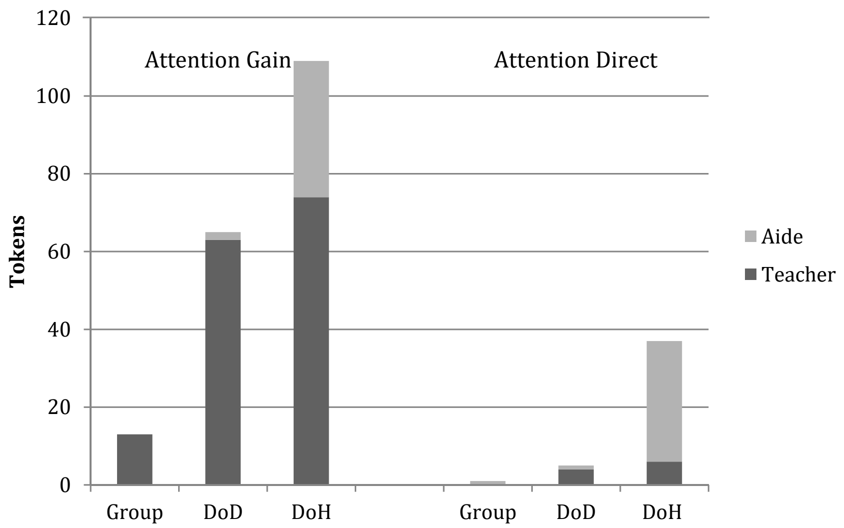


FIGURE 1
Deaf preschool teachers' overall tokens (collapsed across two book-sharing episodes) of Attention-Gaining and Attention-Directing Actions expressed toward the whole group of students, Deaf children of Deaf parents (DoD) and deaf children of hearing parents (DoH).

Refusal). The results of this analysis are summarized in Table 7 and Figure 2, with details reported in the following section.

In terms of positive participation cues produced by the teachers, a total of 41 Invites are documented across both episodes. The DoD students receive 23 Invites (56%), compared to 10 Invites for DoH (24%), and eight are offered to the whole group (20%). The teacher's pattern of Invites seems to vary by context. The Picture Walk is much more unstructured, and the teacher noticeably directs more of her Invites toward individual DoD students ($n$ = 14) compared to DoH ($n$ = 5) students and the whole class ($n$ = 5). This pattern may reflect a higher level of language abilities possessed by the DoD, and the fact that they are reliably visually engaged, as compared to the DoH students. The DoD students often provide more elaborated responses to the teacher's question, while DoH students more typically give minimal (one word) responses, to which the teacher consistently expanded upon or asked follow-up questions to elicit further information.

In the more structured episode, the Role Play, each student has an assigned role and turns are negotiated by the teacher; this structure limits the opportunity for students to contribute spontaneously. As a result, the DoD receive comparably fewer invites ($n$ = 9) than the unstructured episode ($n$ = 14), while the invite number for the DoH ($n$ = 5) remains the same across episodes.

In terms of participation cues to discourage students' negative behavior, the DoH receive a noticeably larger number of corrective prompts from the teachers. Across the two episodes, a total of 76 negative cues are documented (Directive, Delay, and Refusal); among these, the DoH receive 55 prompts (72%), the DoD receive 15 prompts (20%), and the whole class receives six prompts (8%). Across the two episodes, the DoH students receive a similar number of Directives from the teacher (about 10 per episode); however, an additional 10 Directives are issued to the DoH by the aide during the Role Play episode. By contrast, the DoD receive a total of only five such prompts across the two episodes from both teachers. Similarly, the DoH receive more Delay actions ($n$ = 9) from the teacher and the aide, as compared to the DoD ($n$ = 2). This was especially evident when the students are bidding for characters in the beginning of the Role Play activity.

Likewise, the DoH students are the primary recipients of the Refusal cues used by the teacher. The teacher conveys her refusal to yield the floor by refusing to grant eye contact to student(s) who are deliberately waving or physically touching her while she is signing to another student, looking up information in a book, or attempting to distribute a prop to a student. Across both activities, there are a total of 20 occurrences where the teacher refuses a student's inappropriate bid for attention. Of the 20 occurrences, 17 involve DoH students (85%), and three involve DoD students (15%). Most of these Refusals occur during the unstructured Picture Walk activity (16 of 20), when the DoH students seem to be less able to navigate the turn-taking appropriately without the clear cues provided by the structured episode.

TABLE 7 Teacher and teacher's aide participation cues in the unstructured picture walk (21:33) and structured role play (15:40) episodes.

| Participation cues | Tokens | | | Frequency | | |
|---|---|---|---|---|---|---|
| | Group | DoD | DoH | Group | DoD | DoH |
| **Teacher (unstructured)** | | | | | | |
| **Positive** | | | | | | |
| Invite | 5 | 14 | 5 | 0.21 | 0.58 | 0.21 |
| **Negative** | | | | | | |
| Directive | 4 | 1 | 8 | 0.31 | 0.08 | 0.62 |
| Delay | 0 | 0 | 1 | 0.00 | 0.00 | 1.00 |
| Refuse | 0 | 0 | 16 | 0.00 | 0.00 | 1.00 |
| Negative total | 4 | 1 | 25 | 0.13 | 0.03 | 0.83 |
| **Teacher (structured)** | | | | | | |
| **Positive** | | | | | | |
| Invite | 3 | 9 | 5 | 0.18 | 0.53 | 0.29 |
| **Negative** | | | | | | |
| Directive | 0 | 3 | 11 | 0.00 | 0.21 | 0.79 |
| Delay | 2 | 1 | 0 | 0.67 | 0.33 | 0.00 |
| Refuse | 0 | 3 | 1 | 0.00 | 0.75 | 0.25 |
| Negative total | 2 | 7 | 12 | 0.09 | 0.33 | 0.57 |
| **Teacher aide (structured)** | | | | | | |
| **Positive** | | | | | | |
| Invite | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 |
| **Negative** | | | | | | |
| Directive | 0 | 0 | 10 | 0.00 | 0.00 | 1.00 |
| Delay | 0 | 1 | 8 | 0.00 | 0.11 | 0.89 |
| Refuse | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 |
| Negative total | 0 | 7 | 18 | 0.00 | 0.05 | 0.95 |
| Overall positive total | 8 | 23 | 10 | 0.20 | 0.56 | 0.24 |
| Overall negative total | 6 | 15 | 55 | 0.08 | 0.20 | 0.72 |

## Discussion

This classroom observational study focuses on how a Deaf preschool teacher and her teacher's aide promote the development of visual modality capital (gaining and directing attention) and a visual language ecology (through participation cues) with their deaf preschool-aged students. We note that across the two book-sharing contexts we observed, all the preschoolers are frequently prompted by the teacher with linguistic reminders that they should be paying attention. However, two further insights emerge from these observations. First, the teachers' seemingly different behavior toward Deaf children of Deaf parents (DoD) and deaf children of hearing parents (DoH) provides compelling evidence that by age four

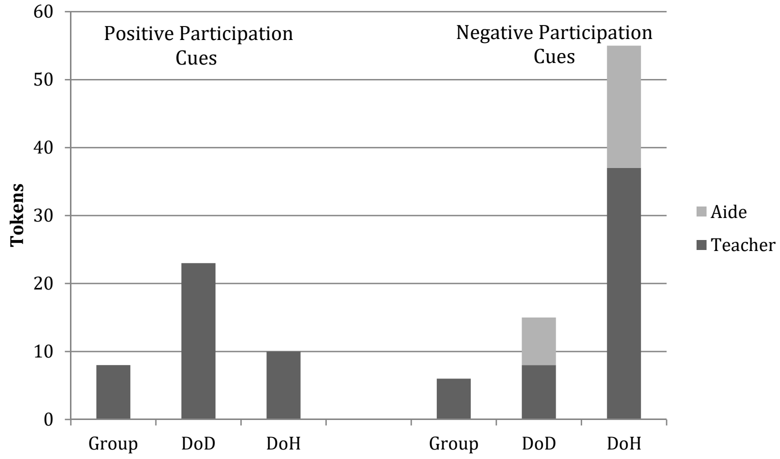


FIGURE 2
Deaf preschool teachers' overall (collapsed across two book-sharing episodes) positive and negative participation cues expressed toward the whole group of students, Deaf children of Deaf parents (DoD), and deaf children of hearing parents (DoH).

DoD are well on their way to possessing visual modality capital through self-control over their visual attention and understanding the turn-taking expectations of a visual language conversation. In many cases, the DoD only need the teacher's more subtle positive participation cue (e.g., "READY?") to alert them that it is time to pay attention. Furthermore, as evidenced by the teacher's increased use of explicit attention socialization strategies toward them, the DoH children appear to still be developing their visual modality capital. The DoH preschoolers are on the receiving end of more attention-socializing directives that are heavily dependent upon physical prompts and corrective prompts likely in response to inattention or inappropriate bids for attention.

Based on the differential interactions between the teachers in this study and their DoD vs. DoH students, we suggest that DoD preschoolers arrive to the classroom with well-established visual modality capital, likely because they have been raised within a developmental niche that promotes visual engagement and self-regulation of attention. This aligns with Spencer et al.'s (1992) observation that between 9 and 18 months of age, deaf caregivers first use physical tapping to attract their deaf infant's attention and then shift to using more linguistic cues as their child approaches 18 months of age. Spencer et al. found that as they became older DoD children would anticipate their caregiver's signing without needing explicit cueing from their caregiver. While we do not specifically code the student's looking patterns, the teachers' actions suggest that the DoD children do not need physical cueing because they are already following the teacher's signing or anticipating her directive on where to look. With the DoH children in our study, it appears that the teachers may be mirroring the kind of socialization patterns observed in Deaf caregiver-infant dyads in that they deploy physical prompts to gain and maintain their attention (in parallel with linguistic cues), presumably because they are responding to failures of looking appropriately or interruptions to turn-taking expectations.

Lieberman (2015) found that native ASL signing preschoolers (age 19–39 months) also use the same attention-getting strategies that we document in our deaf teachers (tapping, waving). It is impressive that at such a young age, these children's initiations with their peers are successful roughly two-thirds of the time. Lieberman states that these young children are already "aware of the need to establish eye contact with their interlocutors in order to communicate in the visual mode" (10) and suggests that they are generalizing from how they have been socialized at home to their classroom interactions with their peers.

A second interesting finding emerges with respect to the nature of the classroom activity. One activity (Picture Walk) is more unstructured, while the other (Role Play) has well-defined, predictable turns for the children to take. Because the unstructured activity likely increases the self-regulation and communication burden on the child, the more-skilled DoD have a clear advantage over the DoH students. In this setting, the DoH frequently interrupt the teacher and needed to be directed more often. By contrast, the Role Play activity is more structured with predictable turn-taking patterns. Here, we do not observe the DoH children interrupting; however, the teacher and the teacher's aide are still fairly directive toward the DoH seemingly to help them keep on task and support their engagement in the structured activity.

Lastly, we note that the teacher frequently repeated her instructions. While it is not within the scope of this analysis, we do feel that further research is needed on why a signing teacher may be repeating her utterances so much (our intuition says this repetition was even more than what "preschool teacher register" would engender). We know from Pizer et al.'s (2011) study with infants and young toddlers that deaf caregiver repetitions occur even when the child's gaze was connected (that is, that their repetition was not due to the child missing the caregiver's signing because of inattention). Pizer et al. (2011) suggest that caregiver repetitions may be an invitation to the child to imitate or respond. In the case of our preschool classroom with six children closer to age five, the teacher's repetition of signing may serve to accommodate a child who has missed the teacher's signing through inattention, or it may be a characteristic of a child-directed language register that she intuitively deploys knowing that half of the students in her class are still acquiring ASL and still establishing visual modality capital.

## Conclusion and implication for practice

Based on the results from this in-depth observation of teacher-student interaction, our study suggests that, at least for this Deaf teacher and her aide, socialization patterns for promoting student's visual modality capital are reminiscent of how Deaf caregivers engage with their deaf children in infancy. Overall, like Lieberman (2015), we observe that the Deaf preschoolers from Deaf parented families seemed to already know how to engage visually and are thus "ready to learn" and appear to respond well to the teacher's explicit and implicit (linguistic, discourse-embedded) attention prompts that support interaction in a visual language [see Horton and Singleton (2022) this volume, for a review of turntaking practices in a signed language]. These DoD students are more frequently invited to participate because it appears that they anticipated the teacher's invitation (i.e., they were already looking at her when she was doing the inviting and could thus appropriately respond). For the DoH preschoolers, who appear to be still developing their self-regulation of attention capacity (i.e., leveraging visual modality capital for language acquisition), the teacher and her aide more often use physical prompts (such as a physical tap) to attract and direct their attention because, based on our observation, it appears that the students have not visually anticipated her invitation to participate.

As this is only a single observational study, we are careful about broader generalizations that could be made from our observations; even so, we do offer a few ideas for classroom implications based on our findings and those of others. Teachers, or teacher's aides, may want to sit close enough to emergent signers so that they can use a physical touch to alert them to attend. Gradually, or even in parallel, a teacher could increase their use of linguistic prompts, and decrease the use of physical signals, to promote the child's self-regulation of attention.

Structured group participation activities can also help a deaf child engage with their teacher and peers in visually predictable ways (e.g., following a fixed order for activities that require individual turns). Still, it would be important to gradually mix in more unstructured activities to give children increasing experience with spontaneously requesting a bid for attention, holding the floor, and rapidly shifting their gaze to other conversation participants.

Finally, activities that require children to shift their gaze amongst a series of visual targets may help promote their visual modality capital. For example, a child might be expected to shift their attention between the signing teacher, a large flipchart, and a collection of illustrations (e.g., pictures of farm animals) to be selected from (for putting on the chart). Also, it might be useful to ask two linguistic models to share the storytelling in a book reading event so that the children must shift their attention between two narrators and the book.

While this study offers an in-depth look at deaf teacher-deaf student interaction using a visual modality lens, we recognize that it is based on a sample drawn from a limited context (an ASL-using school with Deaf preschool teachers). In the future, it will be important to examine visual language ecologies across a broader range of structured and unstructured educational contexts, including children with different language and modality experiences (e.g., deaf children with cochlear implants, hearing children of deaf parents acquiring both English and ASL), and from different cultural settings where gaze norms may vary significantly from the US context that we explored here. In addition, it is important to examine the role of other skilled signers besides the teacher in helping a novice strengthen their visual attention and language skills. Lieberman's (2015) study of native ASL signing deaf toddlers (ages 21–39 months) in a preschool provides ample evidence that children even this young use attention-getting strategies to engage with their peers.

Considering "developmentally appropriate" or "best practices" in early childhood education in more general terms, we recognize that the field would not necessarily advocate for a heavy reliance on "teacher-centered" group-based instruction, favoring instead free-choice, center-based, discovery-type learning. In the context of deaf education, however, it may be the case that a child draws different benefits from group instruction or teacher-mediated interaction especially because such contexts provide greater demand within the visual modality insofar as these discourse frameworks require increased attention shifting and anticipatory looking on the part of the child.

A final point to emphasize here is that we conceptualize the promotion of a deaf child's visual modality capital by immersing them in a natural visual language and *scaffolding their visual engagement*. Like Dye et al. (2008), we do not feel that "stripping down" a child's visual world or eliminating all visual distractions (e.g., placing them in the front of the class or setting up physical barriers to reduce visual access to background distractions) is an ecologically valid approach to strengthening their visual modality capital [in fact, Dye et al. (2008) argue that such arrangements may even exacerbate the situation]. Because deaf individuals have adapted their visual systems to maintain vigilance in attending to their periphery while attending to a central point of focus (Proksch and Bavelier, 2002), it is the *unexpected* visual distractions in the periphery that appear to be the most intrusive. Dye et al. (2008) suggest that we allow a child *to learn* to navigate the expected level of "visual noise" and adapt to the visual demands of their learning environment. By structuring their visual modality capital, we *increase the predictability* of their visual language interactions, which may subsequently reduce their sensitivity to peripheral distractions. We would also argue that to strengthen the ecological validity of this "structuring approach" we must look to how Deaf parents and Deaf teachers have routinely solved this challenge vis-à-vis their "indigenous practices" (Humphries, 2004) or intuitive practices (Papoušek and Papoušek, 1987). By applying these culturally- and modality-appropriate environmental supports for language and visual modality socialization in the classroom, teachers can create developmental niches that unlock intuitive adaptations for learners who are deaf and who learn language through the visual modality.

## Data availability statement

The video source datasets presented in this article are not readily available as they contain identifiable information about participants. Requests to access de-identified datasets should be directed to JS, jenny.singleton@stonybrook.edu.

## Ethics statement

The studies involving human participants were reviewed and approved by University of Illinois at Urbana-Champaign. Written informed consent to participate in this study was provided by the participants (teachers) or their legal guardian/next of kin (children).

## Author contributions

JS designed the study, collected the data, participated in data coding and analysis, and led the writing of the manuscript. PC conducted data coding and analyses and significantly contributed to the writing of the manuscript. Both authors contributed to the article and approved the submitted version.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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## References

Ackerman, J., Kyle, J., Woll, B., and Ezra, M. (1990). "Lexical Acquisition in sign and speech: Evidence from a longitudinal study of infants in deaf families," in *Sign Language Research: Theoretical Issues*, ed. C. Lucas (Washington, DC: Gallaudet University Press), 337–345.

Adamson, L. B., and Bakeman, R. (1991). "The development of shared attention during infancy," in *Annals of Child Development*, ed. R. Vasta (London: Kingsley), 1–41.

Adamson, L. B., Bakeman, R., Deckner, D. F., and Romski, M. (2009). Joint engagement and the emergence of language in children with autism and down syndrome. *J. Autism Dev. Disord.* 39, 84–96. doi: 10.1007/s10803-009-0721-8

Anderson, P. (2002). Assessment and development of executive function (EF) during childhood. *Child Neuropsychol.* 8, 71–82. doi: 10.1076/chin.8.2.71.8724

Bakeman, R., Adamson, L. B., Konner, M., and Barr, R. G. (1990). !Kung infancy: The social context of object exploration. *Child Dev.* 61, 784–809. doi: 10.2307/1130964

Baldwin, D. A. (1995). "Understanding the link between joint attention and language," in *Joint Attention: Its Origins and Role in Development*, eds C. Moore and P. J. Dunham (Mahwah, NJ: Erlbaum), 131–158.

Baron-Cohen, S. (2000). "Theory of mind and autism: A fifteen-year review," in *Understanding Other Minds: Perspectives from Developmental Cognitive Neuroscience*, 2nd Edn, eds S. Baron-Cohen, H. Tager-Flusberg, and J. Donald (New York, NY: Oxford University Press), 3–20.

Bornstein, R. (1990). Neuropsychological performance in children with tourette syndrome. *Psychiatry Res.* 33, 73–81. doi: 10.1016/0165-1781(90)90150-4

Bronson, M. B. (2000). *Self-Regulation in Early Childhood: Nature and Nurture*. New York, NY: Guilford Press.

Brooks, R., and Meltzoff, A. (2002). The importance of eyes: How infants interpret adult looking behavior. *Dev. Psychol.* 38, 958–966. doi: 10.1037/0012-1649.38.6.958

Brooks, R., and Meltzoff, A. (2008). Infant gaze following and pointing predict accelerated vocabulary growth through two years of age: A longitudinal, growth curve modeling study. *J. Child Lang.* 35, 207–220. doi: 10.1017/S030500090700829X

Brooks, R., and Meltzoff, A. N. (2005). The development of gaze-following and its relation to language. *Dev. Sci.* 8, 535–543. doi: 10.1111/j.1467-7687.2005.00445.x

Brooks, R., Singleton, J., and Meltzoff, A. (2019). Enhanced gaze-following behavior in Deaf infants of Deaf parents. *Dev. Sci.* 23:e12900. doi: 10.1111/desc.12900

Carpenter, M., Nagell, K., and Tomasello, M. (1998). Social cognition, joint attention and communicative competence from 9 to 15 months of age. *Monogr. Soc. Res. Child Dev.* 63:i–vi, 1–143. doi: 10.2307/1166214

Chavajay, P., and Rogoff, B. (1999). Cultural variation in management of attention by children and their caregivers. *Dev. Psychol.* 35, 1079–1091. doi: 10.1037/0012-1649.35.4.1079

Corina, D., and Singleton, J. (2009). Developmental social cognitive neuroscience: Insights from deafness. *Child Dev.* 80, 952–967. doi: 10.1111/j.1467-8624.2009.01310.x

Dawson, G., Meltzoff, A., Osterling, J., Rinaldi, J., and Brown, E. (1998). Children with autism fail to orient to naturally occurring social stimuli. *J. Autism Dev. Disord.* 28, 479–485. doi: 10.1023/A:1026043926488

de León, L. (2011). "Language socialization and multiparty participation frameworks," in *The Handbook of Language Socialization*, eds A. Duranti, E. Ochs, and B. Schieffelin (Hoboken, NJ: Blackwell Publishing), 81–111. doi: 10.1002/9781444342901.ch4

DeLuzio, D., and Girolametto, L. (2006). Joint attention strategies used by a preschool educator who is Deaf. *J. Deaf Stud. Deaf Educ.* 11, 214–223. doi: 10.1093/deafed/enj022

Dye, M., Hauser, P., and Bavelier, D. (2008). "Visual attention in deaf children and adults: Implications for learning environments," in *Deaf Cognition: Foundations and Outcomes*, eds M. Marschark and P. Hauser (New York, NY: Oxford University Press), 250–263. doi: 10.1093/acprof:oso/9780195368673.003.0009

Erting, C. J., Prezioso, C., and Hynes, M. (1990/1994). "The interactional context of deaf mother-infant communication," in *From Gesture to Language in Hearing and Deaf Children*, eds V. Volterra and C. J. Erting (New York, NY: Springer-Verlag), 97–106. doi: 10.1007/978-3-642-74859-2_9

Fernald, A., Taeschner, T., Dunn, J., Papousek, M., de Boysson-Bardies, B., and Fukui, I. (1989). A cross-language study of prosodic modifications in mothers' and fathers' speech to preverbal infants. *J. Child Lang.* 16, 477–501. doi: 10.1017/s0305000900010679

Flack, M. (1932). *Ask Mr. Bear*. New York, NY: Aladdin.

Gaskins, S., and Paradise, R. (2010). "Learning through observation in daily life," in *The Anthropology of Learning in Childhood*, eds D. F. Lancy, D. F. Bock, and S. Gaskins (Plymouth: AltaMira Press), 85–110.

Grieser, D. L., and Kuhl, P. (1988). Maternal speech to infants in a tonal language: Support for the universal prosodic features in motherese. *Dev. Psychol.* 24, 14–20. doi: 10.1037/0012-1649.24.1.14

Guarinello, A., Berberian, A., Santana, A., and Massi, G. (2006). Deafness and attention in Deaf children. *Am. Ann. Deaf* 151, 499–507. doi: 10.1353/aad.2007.0004

Harris, M., Clibbens, J., Chasin, J., and Tibbits, R. (1989). The social context of early sign language development. *First Lang.* 9, 81–97. doi: 10.1177/014272378900902507

Harris, M., and Mohay, H. (1997). Learning to look in the right place: A comparison of attentional behavior in deaf children with deaf and hearing mothers. *J. Deaf Stud. Deaf Educ.* 2, 95–103. doi: 10.1093/oxfordjournals.deafed.a014316

Haviland, J. B. (2020). "Signs, interaction, coordination, and gaze: Interactive foundations of "Z"—an emerging (sign) language from Chiapas, Mexico," in *Emerging Sign Languages of the Americas*, eds O. Le Guen, J. Safar, and M. Coppola (Lancaster: de Gruyter), 35–96. doi: 10.1515/9781501504884-002

Hoff, E. (2006). How social contexts support and shape language development. *Dev. Rev.* 26, 55–88. doi: 10.1016/j.dr.2005.11.002

Holcomb, T. (2013). *Introduction to American Deaf Culture*. New York, NY: Oxford University Press.

Horton, L., and Singleton, J. (2022). Acquisition of turn taking in sign language conversations: An overview of language modality and turn structure. *Front. Psychol.* 13:935342. doi: 10.3389/fpsyg.2022.935342

Humphries, T. (2004). "The modern Deaf self: Indigenous practices and educational imperatives," in *Literacy and Deaf People: Cultural and Contextual Perspectives*, ed. B. Brueggemann (Washington, DC: Gallaudet University Press), 29–46. doi: 10.2307/j.ctv2rcnnrw.4

Jamieson, J. (1994). Teaching as a transaction: Vygotskian perspectives on deafness and mother-child interaction. *Except. Child.* 60, 434–449. doi: 10.1177/001440299406000506

Klin, A., Lin, D., Gorrindo, P., Ramsay, G., and Jones, W. (2009). Two-year-olds with autism orient to nonsocial contingencies rather than biological motion. *Nature* 459, 257–261. doi: 10.1038/nature07868

Koester, L. S., Karkowski, A. M., and Traci, M. A. (1998). How do Deaf and hearing mothers regain eye contact when their infants look away? *Am. Ann. Deaf* 143, 5–13. doi: 10.1353/aad.2012.0071

Koester, L. S., Traci, M. A., Brooks, L. R., Karkowski, A. M., and Smith-Gray, S. (2004). "Mother-infant behaviors at 6 and 9 months: A microanalytic view," in *The World of Deaf Infants: A Longitudinal Study*, eds K. P. Meadow-Orlans, P. E. Spencer, and L. S. Koester (New York, NY: Oxford University Press), 40–56.

Lieberman, A. (2015). Attention-getting skills of deaf children using American Sign Language in a preschool classroom. *Appl. Psycholinguist.* 36, 855–873. doi: 10.1017/S0142716413000532

Lieberman, A., Hatrak, M., and Mayberry, R. (2011). "The development of eye gaze control for linguistic input in deaf children," in *Proceedings of the 35th Annual Boston University Conference on Language Development*, eds N. Danis, K. Mesh, and H. Sung (Somerville, MA: Cascadilla Press), 391–404.

Lieberman, A., Hatrak, M., and Mayberry, R. (2014). Learning to look for language: Development of joint attention in young deaf children. *Lang. Learn. Dev.* 10, 19–35. doi: 10.1080/15475441.2012.760381

Loots, G., and Devise, I. (2003). The use of visual-tactile communication strategies by deaf and hearing fathers and mothers of deaf infants. *J. Deaf Stud. Deaf Educ.* 8, 31–42. doi: 10.1093/deafed/8.1.31

Loots, G., Devise, I., and Jacquet, W. (2005). The impact of visual communication on the intersubjective development of early parent-child interaction with 18-to-24 month-old deaf toddlers. *J. Deaf Stud. Deaf Educ.* 10, 357–375. doi: 10.1093/deafed/eni036

Masataka, N. (1992). Motherese in a signed language. *Infant Behav. Dev.* 15, 453–460. doi: 10.1016/0163-6383(92)80013-K

Mather, S. (1987). Eye gaze and communication in a deaf classroom. *Sign Lang. Stud.* 54, 11–30. doi: 10.1353/sls.1987.0008

Mather, S. (1989). "Visually oriented teaching strategies with deaf preschool children," in *The Sociolinguistics of the Deaf Community*, ed. C. Lucas (New York, NY: Academic Press), 165–187. doi: 10.1002/ajmg.1320440315

Mather, S., and Thibeault, A. (2000). "Style in book reading with deaf and hard of hearing students: The visual way," in *Language Acquisition by Eye*, eds C. Chamberlain, J. P. Morford, and R. I. Mayberry (Mahwah, NJ: Lawrence Erlbaum), 191–200.

Meltzoff, A. N., and Brooks, R. (2008). Self-experience as a mechanism for learning about others: A training study in social cognition. *Dev. Psychol.* 44, 1257–1265. doi: 10.1037/a0012888

Mohay, H., Milton, L., Hindmarsh, G., and Ganley, K. (1998). "Deaf mothers as communication models for hearing families with deaf children," in *Issues Unresolved: New Perspectives on Language and Deaf Education*, ed. A. Weisel (Washington, DC: Gallaudet University Press), 76–87. doi: 10.2307/j.ctv2rh28h0.13

Morales, M., Mundy, P., Delgado, C. E., Yale, M., Messinger, D., Neal, R., et al. (2000). Responding to joint attention across the 6- through 24-month age period and early language acquisition. *J. Appl. Dev. Psychol.* 21, 283–298. doi: 10.1016/S0193-3973(99)00040-4

Mundy, P. (2003). The neural basis of social impairments in autism: The role of the dorsal medial-frontal cortex and anterior cingulated system. *J. Child Psychol. Psychiatry* 44, 793–809. doi: 10.1111/1469-7610.00165

Mundy, P., Kasari, C., Sigman, M., and Ruskin, E. (1995). Nonverbal communication and early language acquisition in children with down syndrome and in normally developing children. *J. Speech Hear. Res.* 38, 157–167. doi: 10.1044/jshr.3801.157

Mundy, P., and Sheinkopf, S. (1998). "Early skill acquisition and developmental disorders," in *Handbook of Mental Retardation and Development*, eds J. Burack, B. Hodapp, and E. Zigler (New York, NY: Cambridge University Press), 183–209.

Mundy, P., Sigman, M., and Kasari, C. (2000). "The theory of mind and joint-attention deficits in autism," in *Understanding Other Minds: Perspectives from Developmental Cognitive Neuroscience*, 2nd Edn, eds S. Baron-Cohen, H. Tager-Flusberg, and D. J. Cohen (New York, NY: Oxford University Press), 181–203.

Newport, E., Gleitman, H., and Gleitman, L. (1977). "Mother, I'd rather do it myself: Some effects and non-effects of maternal speech style," in *Talking to Children: Language Input and Acquisition*, eds C. E. Snow and C. A. Ferguson (Cambridge, MA: Cambridge University Press), 109–150.

Ochs, E., and Schieffelin, B. (1984). "Language acquisition and socialization," in *Culture Theory: Essays on Mind, Self, and Emotion*, eds R. A. Shweder and R. A. LeVine (Cambridge, MA: Cambridge University Press), 276–320.

Papoušek, H., and Papoušek, M. (1987). "Intuitive parenting: A dialectic counterpart to the infant's precocity in integrative capacities," in *Handbook of Infant Development*, 2nd Edn, ed. J. D. Osofsky (New York, NY: John Wiley and Sons), 669–720.

Pizer, G., Meier, R. P., and Shaw Points, K. (2011). "Child-directed signing as a linguistic register," in *Formational Units in Sign Languages*, eds R. Channon and J. van der Hulst (Berlin: Ishara Press), 65–83. doi: 10.1515/9781614510680.65

Posner, M. I., and Rothbart, M. K. (2000). Developing mechanisms of self-regulation. *Dev. Psychopathol.* 12, 427–441. doi: 10.1017/S0954579400003096

Posner, M. I., and Rothbart, M. K. (2007). Research on attention networks as a model for the integration of psychological science. *Annu. Rev. Psychol.* 58, 1–23. doi: 10.1146/annurev.psych.58.110405.085516

Prezbindowski, A. K., Adamson, L. B., and Lederberg, A. R. (1998). Joint attention in deaf and hearing 22 month-old children and their hearing mothers. *J. Appl. Dev. Psychol.* 19, 337–387. doi: 10.1016/S0193-3973(99)80046-X

Proksch, J., and Bavelier, D. (2002). Changes in the spatial distribution of visual attention after early deafness. *J. Cogn. Neurosci.* 14, 687–701. doi: 10.1162/08989290260138591

Rogoff, B. (1990). *Apprenticeship in Thinking: Cognitive Development in Social Context*. New York, NY: Oxford University Press.

Rogoff, B. (2003). *The Cultural Nature of Human Development*. New York, NY: Oxford University Press.

Rogoff, B., Mistry, J., Göncü, A., and Mosier, C. (1993). Guided participation in cultural activity by toddlers and caregivers. *Monogr. Soc. Res. Child Dev.* 58:v–vi, 1–174. doi: 10.2307/1166109

Rothbart, M. K., Posner, M., and Boylan, A. (1990). "Regulatory mechanisms in infant development," in *The Development of Attention: Research and Theory. Advances in Psychology*, ed. J. T. Enns (North-Holland: Elsevier), 47–66. doi: 10.1016/S0166-4115(08)60450-1

Ruff, H. A., and Rothbart, M. K. (1996). *Attention in Early Development: Themes and Variations*. New York, NY: Oxford University Press.

Singleton, J. L., and Meier, R. P. (2021). "Sign language acquisition in context," in *Discussing Bilingualism in Deaf Children: Essays in Honor of Robert Hoffmeister*, eds C. Enns, J. Henner, and L. McQuarrie (New York, NY: Routledge), 17–34. doi: 10.4324/9780367808686-2-3

Singleton, J. L., and Morgan, D. D. (2006). "Natural signed language acquisition within the social context of the classroom," in *Advances in the Sign Language Development of Deaf Children*, eds B. Schick, M. Marschark, and P. E. Spencer (New York, NY: Oxford University Press), 344–375. doi: 10.1093/acprof:oso/9780195180947.003.0014

Smith, D. H., and Ramsey, C. L. (2004). Classroom discourse practices of a deaf teacher using American Sign Language. *Sign Lang. Stud.* 5, 39–62. doi: 10.1353/sls.2004.0026

Smith, S., and Sutton-Spence, R. (2005). Adult-child interaction in a BSL nursery – getting their attention! *Sign Lang. Linguist.* 8, 129–150. doi: 10.1075/sll.8.1.07smi

Spencer, P. E., Bodner-Johnson, B., and Gutfreund, M. K. (1992). Interacting with infants with hearing loss: What can we learn from mothers who are deaf? *J. Early Interv.* 16, 64–78. doi: 10.1177/105381519201600106

Spencer, P. E., and Harris, M. (2006). "Patterns and effects of language input to deaf infants and toddlers from deaf and hearing mothers," in *Advances in the Sign Language Development of Deaf Children*, eds B. Schick, M. Marschark, and P. E. Spencer (New York, NY: Oxford University Press), 71–101. doi: 10.1093/acprof:oso/9780195180947.003.0004

Super, C. M., and Harkness, S. (1986). The developmental niche: A conceptualization at the interface of child and culture. *Int. J. Behav. Dev.* 9, 545–569. doi: 10.1177/016502548600900409

Super, C. M., and Harkness, S. (2002). Culture structures the environment for development. *Hum. Dev.* 45, 270–274. doi: 10.1159/000064988

Swisher, V. (1992). The role of parents in developing visual turn-taking in their young deaf children. *Am. Ann. Deaf* 137, 92–100. doi: 10.1353/aad.2012.1086

Tomasello, M. (1995). "Joint attention as social cognition," in *Joint Attention: Its Origins and Role in Development*, eds C. Moore and P. J. Dunham (Mahwah, NJ: Erlbaum), 103–130.

Tomasello, M. (1999). *The Cultural Origins of Human Cognition*. Cambridge, MA: Harvard University Press. doi: 10.4159/9780674044371

Tomasello, M., and Farrar, M. J. (1986). Joint attention and early language. *Child Dev.* 57, 1454–1463. doi: 10.2307/1130423

Vaughan van Hecke, A., and Mundy, P. (2007). "Neural systems and the development of gaze-following and related joint attention skills," in *Gaze-Following: Its Development and Significance*, eds R. Flom, K. Lee, and D. Muir (Mahwah, NJ: Erlbaum), 17–51. doi: 10.1109/TNSRE.2021.3108351

Waxman, R., and Spencer, P. E. (1997). What mothers do to support infant visual attention: Sensitivities to age and hearing status. *J. Deaf Stud. Deaf Educ.* 2, 104–114. doi: 10.1093/oxfordjournals.deafed.a014311

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# Simultaneous structures in sign languages: Acquisition and emergence

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The visual-gestural modality affords its users simultaneous movement of several independent articulators and thus lends itself to simultaneous encoding of information. Much research has focused on the fact that sign languages coordinate two manual articulators in addition to a range of non-manual articulators to present different types of linguistic information simultaneously, from phonological contrasts to inflection, spatial relations, and information structure. Children and adults acquiring a signed language arguably thus need to comprehend and produce simultaneous structures to a greater extent than individuals acquiring a spoken language. In this paper, we discuss the simultaneous encoding that is found in emerging and established sign languages; we also discuss places where sign languages are unexpectedly sequential. We explore potential constraints on simultaneity in cognition and motor coordination that might impact the acquisition and use of simultaneous structures.

KEYWORDS

**simultaneity, classifier constructions, language emergence, language acquisition, discourse**

## Introduction

Signed and spoken languages differ typologically in a key aspect of their structure. Spoken languages are largely organized sequentially (Pinker and Bloom, 1990), both in their phonology (strings of phonemes) and in their morphology (a tendency toward prefixation and suffixation). Signed languages show much more simultaneous structuring, whether in their phonology or morphology (Klima and Bellugi, 1979; Meier, 2002; Aronoff et al., 2005). This difference is not absolute. There are simultaneously organized structures in spoken languages as well: notably the tonal morphology of many African languages (Odden, 1995), as well as some Mesoamerican languages such as Chatino (Cruz, 2011) and Rarámuri (Caballero and German, 2021). For instance, Rarámuri *tisô* 'walk with a cane (bare stem)' and *tisò* 'walk with a cane (imperative singular)' are distinguished by falling tone vs. low tone, respectively (Caballero and German, 2021: 160). Likewise, there are sequentially organized constructions in signed languages, most obviously in their syntax and in compounding, but also instances of prefixation and suffixation that have been reported in American and Israeli Sign Languages (Aronoff et al., 2005).

Overall, however, children and adults who acquire a sign language need to learn, produce, and comprehend more simultaneous structures than individuals acquiring a spoken language. Simultaneity can be seen as an outcome of the constraints of the manual articulators (for example, the slow rate of signing—Klima and Bellugi, 1979), of the availability of multiple articulators to signed languages, of the capacities of the visual system, and/or of the resources for iconic representation that the visual-gestural modality affords; see Meier (2002) for discussion. The bandwidth available to the human visual system apparently means that such layered information can be apprehended successfully (Meier, 1993). Here we investigate what challenges simultaneity may pose for the grammars of signed languages, for the children acquiring signed languages as first languages, for the adults learning them as second languages, and for the emergence of new signed languages.

Articulated and perceived in the visual-gestural modality, signed languages have multiple articulators that can move independently or semi-independently at the same time. The hands, arms, torso, head, and various facial muscles may encode different types of linguistic information simultaneously, from phonological contrasts to spatial relations and information structure (Aronoff et al., 2005; Sandler and Lillo-Martin, 2006; Vermeerbergen et al., 2007). Vermeerbergen et al. (2007) distinguish three types of simultaneity: manual simultaneity, manual-oral simultaneity, and the simultaneous use of several non-manual articulators or of a manual and a non-manual articulator other than the mouth. In this paper, we are mostly concerned with manual simultaneity, where each hand contributes meaning. Building on the work of Miller (1994), we can distinguish the following five subtypes of manual simultaneity according to the types of signs combined and the temporal coordination between the hands: (a) two lexical signs are produced simultaneously, (b) two classifiers are produced at the same time, (c) one hand produces a sign and then holds it while the other hand continues signing one or more signs (weak-hand hold), (d) the non-dominant hand produces an enumeration morpheme while the dominant hand encodes the items on the list, and (e) one hand produces an index sign (or "pointer buoy," Liddell, 2003) while the other produces a string of signs. Sign languages may differ in the extent to which they use simultaneous encoding; for instance, Nyst (2007) reports that Adamorobe Sign Language exhibits little manual simultaneity.

Manual-oral simultaneity involves synchronized productions of the hands and mouth (either via mouthings or mouth gestures), which may contribute the same or complementary information. In German Sign Language (DGS), for example, one might sign GUT 'good' while mouthing the equivalent German word, and both contribute the same information. One may also sign GUT while mouthing *alles* 'all', where the mouthing contributes an argument of the predicate GUT. More generally, other non-manuals may be combined simultaneously, e.g., raised eyebrows and a headshake in negative polar questions, and they may (further) combine with manual signs. While we focus on manual simultaneity in this paper, we will sometimes draw on manual/non-manual simultaneity when discussing constructed action and the acquisition of simultaneous structure in discourse.

The availability of multiple articulators is not necessary for simultaneous structure in signed languages. Even signs that are produced by just one hand may show simultaneous structure. For example, one-handed "classifier constructions" (CCs)[1] express properties of the referent through the handshape (whether it is a human, or a vehicle, or a small animal), while the location and movement of the sign simultaneously encode the location and/or the movement direction of that referent, as well as additional information about, for instance, its manner of movement. Likewise, inflectional and derivational morphology in signed languages is typically simultaneous in its structure. The distinction between one- and two-handedness is a feature of some inflectional categories [e.g., certain dual verb forms in American Sign Language (ASL) and some plural nouns in Sign Language of the Netherlands (NGT), van Boven, 2021] and some derivational categories (e.g., the characteristic adjectives of ASL, Klima and Bellugi, 1979; Padden and Perlmutter, 1987). However, inflection and derivation are largely signaled by changes in movement patterning that affect the overall movement contour of a sign and that are independent of the handedness of signs. These modulations of movement structure are non-affixal; examples include the changes in movement direction and in hand orientation by which directional verbs in many signed languages mark argument structure (e.g., Lillo-Martin and Meier, 2011). Other examples include the short, repeated, restrained movement that marks deverbal nouns in ASL (Supalla and Newport, 1978; Abner, 2019) and the varying patterns of repeated movement that mark temporal aspect in ASL (Klima and Bellugi, 1979).

In this paper, however, we focus on the simultaneous linguistic structure that arises from the availability of two semi-independent manual articulators in the visual-gestural modality. We begin by discussing children's acquisition of two-handed signs and of the motoric factors that may affect the production of those signs. We then turn to the development of the use of the non-dominant hand in discourse. Lastly, we address children's

1 A range of names has been proposed for this class of constructions, among them *classifier verbs* or *predicates* (Supalla, 1990; Valli and Lucas, 1995), *depicting verbs* (Liddell, 2003), *poly-morphemic signs* (Engberg-Pedersen, 1993) or *poly-componential signs* (Schembri, 2003). We use the term *classifier construction* here because it is widely used but remain agnostic as to whether the term *classifier* is appropriate given the way that term has traditionally been used in the general linguistic literature.

use of the two hands in CCs to describe the Figure and Ground of a motion event. In our discussion of classifier constructions, we compare children and adult learners' acquisition of Figure and Ground to their acquisition of one-handed Path and Manner constructions. This comparison will give us insight into the role that two-handedness plays in the linguistic and developmental constraints affecting classifier constructions. Throughout the discussion we will present findings from both first and second language acquisition and will also bring in relevant data from the emergence of new signed languages.

## Simultaneity in the lexicon: The two hands

A fundamental resource for languages in the visual-gestural modality is the two hands that the human body makes available. Spoken languages have no counterpart to these paired articulators. However, the two hands are only partially independent. There are developmental and linguistic constraints on the simultaneous action of the two hands, and thus there are limits to how much information they can encode simultaneously.

### Two-handed signs in the lexicons of signed languages

In natural signed languages, there are three values for the "hand arrangement" parameter (Klima and Bellugi, 1979). Signs may be one-handed or two-handed; among two-handed signs, the non-dominant hand may move or may be held in place. As has long been observed, the natural signed languages reported to date constrain the form of two-handed signs (Battison, 1978; Eccarius and Brentari, 2007). Two-handed "symmetrical" signs are ones in which both hands move; the two hands must show the same movement, whether in phase (e.g., the ASL sign BATH in **Figure 1A**)[2] or out of phase (e.g., the ASL sign CAR in **Figure 1B**); they must also share the same general location[3] and handshape [thereby barring artificial signs such as TOTAL-COMMUNICATION, which has a T () handshape on the non-dominant hand and a C () on the dominant].[4]

2 **Figures 1**, **2** have been adapted from ASL-LEX (Caselli et al., 2017). We thank the creators of ASL-LEX for granting us permission to use these stills here.

3 The ASL sign SICK is an exception; the dominant hand contacts the forehead and the non-dominant contacts the torso.

4 Tkachman et al. (2021) report an analysis of dictionary data from ASL, British Sign Language (BSL), and Hong Kong Sign Language (HKSL); they found that two-handed symmetrical signs with alternating (out-of-phase) movement are typically repeated (unlike two-handed signs in which the two hands move in phase). They ascribe this result to central pattern generators involved in locomotion.

Signs falling within the second class of two-handed signs show a static non-dominant hand, sometimes called a "base" hand; see the ASL sign NEW-YORK in **Figure 1C**. These signs may have distinct handshapes on the dominant and non-dominant hands, but the non-dominant is only permitted a limited number of relatively basic handshapes. These constraints on sign formation seem related to issues in bimanual coordination; they limit the motoric complexity of monomorphemic signs. These constraints also have the effect of reducing the set of possible phonological contrasts in that no two-handed, symmetrically moving sign may have distinct handshapes on the two hands. These constraints can thus also be seen as limitations on the linguistic complexity of lexical signs (but see Eccarius and Brentari, 2007, for an application of these constraints to CCs).

### Developmental issues in bimanual coordination

Separate control of the two hands during object manipulation emerges late in the first year of life; for example, Fagard et al. (1994) reported considerable development between 6 and 12 months in infants' abilities to coordinate the use of their two hands to perform means-ends tasks that require one hand to hold a box open while the other hand retrieves a toy. Younger infants showed better performance in tasks that could be performed sequentially, rather than tasks requiring the participation of both hands simultaneously.

To perform one-handed movements, children must be able to inhibit the action of the inactive hand. However, when one-handed action is planned, the child's other hand may sometimes mirror that action. This can persist into adolescence for some movements. For example, Connolly and Stratton (1968) reported that, at age five, roughly 55% of boys and 30% of girls showed mirror movements of the non-dominant hand when asked to raise just the middle finger of their dominant hand while their palms were resting flat on a table; by ages eight to nine more than 80% of all children successfully inhibited the non-dominant hand. But at ages 12 to 13 most children still showed mirror movements on a finger-spreading task. Wolff et al. (1983) tested typically developing, right-handed 5- and 6-year-olds three times over 12 months; in general, mirror movements declined over this period. For example, there was a significant decline in the number of 5-year-olds who produced mirror movements in a task in which they were asked to repeatedly pronate and supinate one hand.

Toddlers who were observed longitudinally in a bimanual drumming task did not show stable out-of-phase coordination of the two hands until 20 months (Brakke and Pacheco, 2019, who use the term "anti-phase"); signs such as ASL CAR (**Figure 1B**) show this out-of-phase relationship in that one hand moves down while the other moves up. Some aspects of bimanual coordination (e.g., timing) do not mature until

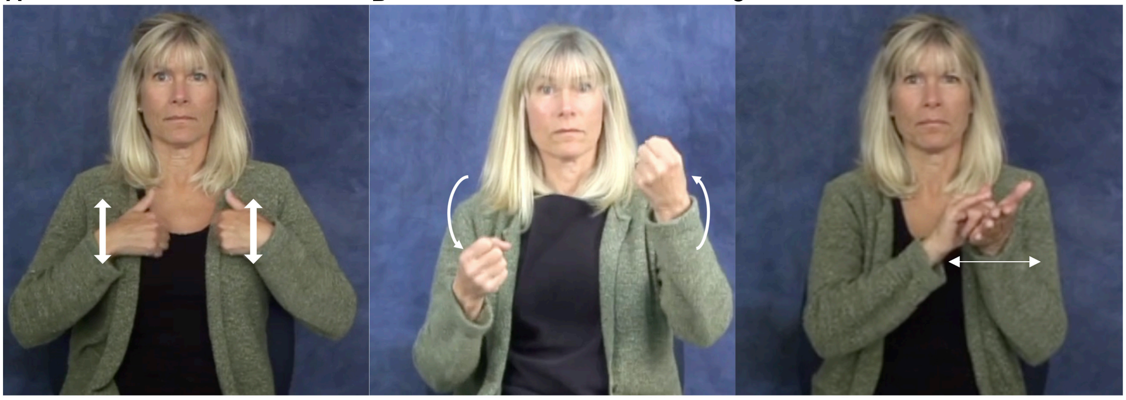


FIGURE 1
The American Sign Language (ASL) signs **(A)** BATH, **(B)** CAR, and **(C)** NEW-YORK. Reproduced with permission from Prof. Naomi Caselli, available at https://asl-lex.org/.

ages nine to eleven, as probed by bimanual finger-tapping tasks (Wolff et al., 1998). Mature bimanual coordination may require functional maturation of the corpus callosum, which has been thought to occur at age ten to eleven (Yakovlev and Lecours, 1967). Transference of information between the two hemispheres through the corpus callosum may enable the inhibition of unintended mirror movements by the hand that is not being intentionally moved by the child (Geffen et al., 1994).

## Acquisition of two-handed signs by deaf children

Relevant data on how bimanual coordination may affect the acquisition of signs is less rich than we would wish. Siedlecki and Bonvillian (1993) report a diary study of the early acquisition of ASL vocabulary by nine children (ages 5–18 months) of deaf parents; eight of the children were hearing and one was deaf. During visits to the children's homes, parents were asked to demonstrate on videotape how their children had produced the signs that the parents had identified in their diaries; deletion of a stationary non-dominant hand was observed, but infrequently (5/62 signs). The parents identified just two errors in which the non-dominant hand moved symmetrically with the dominant hand. Deletion of the non-dominant hand from symmetrical two-handed signs was significantly more frequent (29/135 target signs). Interestingly, Siedlecki and Bonvillian (1993) interpret their data to suggest that children's errors were constrained by whether distinctive phonological information would be lost.

Cheek et al. (2001) examined the prelinguistic gesture (including communicative gestures and "manual babbles") of ten children, five sign-naïve hearing infants and five deaf infants born to deaf, ASL-signing parents. Gestures with a static non-dominant hand were essentially absent from their data; just two tokens were identified from the deaf infants and none from the hearing infants. These authors also examined videotaped, naturalistic data on the production of ASL signs by four native-signing deaf children. Those children were followed longitudinally from as early as 5 months to as late as 17 months. Across this age span, the vast majority of one-handed signs (411/442 tokens, 93%) and most two-handed symmetrical signs (83/117 tokens, 71%) were produced correctly with respect to the hand arrangement parameter. Errors on two-handed symmetrical target signs dropped the non-dominant hand, which can be grammatical in the adult language. The relatively few errors on one-handed target signs involved the addition of a symmetrically moving non-dominant hand. This last type of error might be viewed as consistent with children's mirroring behavior on non-linguistic tasks. Shield et al. (2020) observed the fingerspelling of a native-signing hearing child of deaf parents who has autism spectrum disorder. At 10;2, this boy's non-dominant arm mirrored the large proximal movements of his arm associated with his production of ASL's one-handed fingerspelling system; he does not seem to have mirrored the handshapes themselves. At 14;11, these mirror movements were absent. One question for future research is whether such mirror movements are restricted to motorically and perhaps cognitively demanding signing such as fingerspelling.

Base-hand signs appear to be poorly represented in Cheek et al.'s (2001) data vis-à-vis their representation in the lexicon of ASL; there were just 62 tokens out of a total sample of 629 sign tokens. In contrast, 25% of the entries in Stokoe et al.'s (1965) *Dictionary of ASL on Linguistic Principles* have a non-dominant base hand (Klima and Bellugi, 1979), as do 25% of signs listed in the ASL-LEX lexical database (Caselli et al., 2017; Sehyr et al., 2021). An inspection of the ASL adaptation of the MacArthur Communicative Development Inventory revealed that just two of the 35 earliest-produced signs have a static non-dominant hand; those signs were TREE and COOKIE (Anderson and Reilly, 2002).

As noted, Cheek et al. (2001) only identified 62 tokens with a base hand in the target sign. Error rates on this class of signs were higher than on one-handed signs or symmetrical two-handed signs. To correctly produce adult target signs that have a static non-dominant hand, children must inhibit movement of that hand. Cheek et al.'s subjects were successful on 30 tokens. Of the 32 errors, 12 simply dropped the non-dominant hand. However, in 20 tokens, the two hands moved symmetrically; for example, when one child (age 1;4.6) produced the sign FALL, both hands moved downward in tandem. In contrast, the adult target involves a downward movement of the dominant hand to a static non-dominant hand. Lastly Marentette and Mayberry (2000) reported a case study of one native-signing deaf girl's acquisition of ASL from 12 to 25 months. They briefly describe two relevant classes of errors: (1) errors in which the child froze the movement of the non-dominant hand in signs that have symmetrical movement of the two hands in the adult target (e.g., SHOE, BOOK), and (2) errors in which the non-dominant hand mirrored the movement of the dominant hand (COOKIE, SCHOOL). Productions of these error types peaked at 23 months.

Instances have been reported in which alternating movement of the two hands - that is, movements in which the two hands execute the same movement, but out of phase - was replaced by movements in which the two hands moved in phase (Newport and Meier, 1985). Szameitat (2009) examined the acquisition of ASL phonology by twelve 24-month-old deaf children; six of these children showed at least one instance of "synchronization", by which the two hands moved in phase rather than out of phase. For two children, synchronization was frequent in their sign productions.

In sum, our review finds limited published data that would allow us to assess the impact of motor control issues in bimanual coordination on children's early sign production. What data we do have suggests that children are broadly successful in producing the correct hand arrangement of adult target signs. Evidence on the acquisition of signs with a static non-dominant hand is scant, in part because children seem to attempt few such signs. Here the naturalistic video data reported by Cheek et al. (2001) provides limited evidence that children sometimes err by failing to inhibit movement of the non-dominant hand. The Shield et al. (2020) report raises the possibility that some atypically developing children may have lingering problems in inhibiting the non-dominant hand even in the production of one-handed signs. Very clearly, we need more data - especially perhaps from older children - that would address the question of whether children's production of two-handed signs is constrained by motor control issues.

## The use of the two hands outside the lexicon

In the lexicon of ASL, the non-dominant hand in symmetrical signs is generally redundant. There are few minimal pairs that differ just in whether two signs have one vs. two moving hands; examples noted in the literature include ASL YELLOW/PLAY (**Figure 2**; see Klima and Bellugi, 1979) and DEAD/PERSON(AL) in Swedish Sign Language (Börstell et al., 2016).

Outside the lexicon, however, the non-dominant hand encodes important information in a variety of simultaneously organized constructions. Adding a second hand to a one-handed monomorphemic sign can be morphologically significant; in ASL, the doubling of the two hands is a feature of the marking

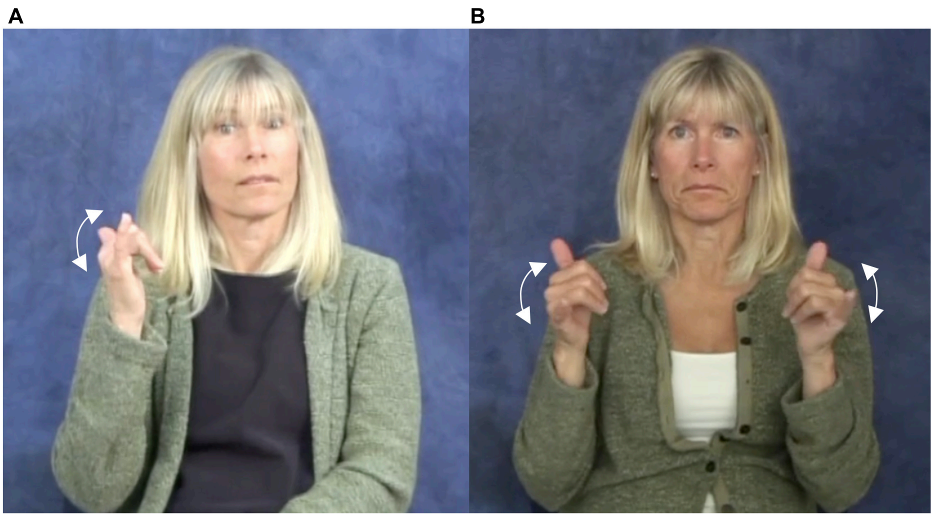


FIGURE 2
The ASL signs **(A)** PLAY and **(B)** YELLOW. Reproduced with permission from Prof. Naomi Caselli, available at https://asl-lex.org/.

of the dual and reciprocal forms of some one-handed verbs (e.g., GIVE), of certain distributive plurals (Klima and Bellugi, 1979), and of the characteristic adjective form of adjectival predicates referring to temporary or incidental states (Klima and Bellugi, 1979; Padden and Perlmutter, 1987). Doubling of the hands, in combination with alternating movement, can mark the plurals of some nouns in various signed languages (Pfau and Steinbach, 2006).

The non-dominant hand plays a crucial role in CCs and may also assume important functions in discourse regulation. It is these constructions to which we now turn. Here we might expect motoric complexity to be a limiting factor for the young child. We first turn to the acquisition of discourse functions of the non-dominant hand and then discuss Figure-Ground constructions, where the static non-dominant hand encodes information about the landmarks against which objects move.

## Acquisition of narrative and discourse functions of simultaneity

Some of the earliest studies on manual simultaneity mention its discourse-pragmatic functions. Engberg-Pedersen (1994) and Miller (1994) look respectively at DTS (*Dansk tegnsprog*) and LSQ (*Langue des signes québécoise*). They claim that one of the main functions of manual simultaneity is to distinguish foregrounded from backgrounded information such that the dominant hand typically carries information that is central to an ongoing discourse. The non-dominant hand may modify this information or otherwise contribute to the "management of the discourse situation" (Miller, 1994: 103). It may, for instance, maintain a topic referent via a weak-hand hold as illustrated in (1a) (Friedman, 1975; Gee and Shepard-Kegl, 1983), or indicate the spatial or temporal frame of a described event (1b).

(1) a. R: WE LOOK-AT $IX_{car}$ WE LOOK-AT $IX_{car}$
L: CAR - - - - - - - - - - - - - - - - - - - - - - -
'We looked at the car. We looked at the car.'

b. R: ENGLISH CLASS GO HOME STUDY
L: TWO (o'clock)- - - - FOUR SIX- - - - - -
R: EAT
L: SEVEN
'At two (I go to) English class; from four to six (I) go home and study; at seven (I) eat.'
(Friedman, 1975: 953)

Few studies to date have focused on the acquisition of discourse structure in signed languages and yet fewer have discussed discourse-structural uses of bimanual simultaneity in child language development. Prinz and Prinz (1985) report that children acquiring ASL start using weak-hand holds for topic maintenance and topic chaining around age ten. Younger signers (age 8—9) may briefly display a sign on the non-dominant hand, but then drop the hand despite using the same sign at a later point within the same discourse episode, indicating that its referent was a topic in the child's narrative. Tang et al. (2007) observe that learners of Hong Kong Sign Language (HKSL), even as late as age 13, rarely used such discourse-structuring weak-hand holds ("fragment buoys" in Liddell, 2003). The late emergence of weak-hand holds for topic maintenance parallels the emergence of other discourse-structuring devices such as backchanneling head nods or lexical signs of agreement (e.g., OKAY, SAME) around the same age (Prinz and Prinz, 1985). Prinz and Prinz concluded that the strategies employed by deaf children converge with the development of similar skills in spoken languages, e.g., how discourse topics are initiated, maintained, and terminated. Although it is possible that the late emergence of discourse weak-hand holds in sign languages is conditioned in part by persistent motor coordination difficulties in articulating a static base hand, the timeline by which these usages are acquired in signed languages does not seem at variance with the timeline by which narrative skills are acquired in spoken languages (Clark, 2016) or by which other discourse-structuring devices are acquired in signed languages.

The nascent use of both hands for creating topic-comment structures is also observed in homesigners around the same age. Scroggs (1981) describes the productions of a 9-year-old deaf boy, Alexander, who at the time of recording had had little exposure either to ASL or signed English from his hearing parents, and who had just been enrolled in a public day-school program for deaf children in which a form of signed English was used. His narrative productions frequently contained a topic established on the dominant hand that was then moved to the non-dominant hand while the dominant hand articulated a description or comment. In one example, Alexander described the speed of a motorcycle by first producing the motorcycle on his right hand, then moving it to the left hand while producing an idiosyncratic sign for 'speed' on the right hand. Another example was Alexander's description of a surfer rescued by a helicopter, in which he represented the discourse topic 'surfer' on his left hand and the helicopter whirling to the rescue on the right hand.

Even without the additional challenges of bimanual coordination, young children struggle to encode concurrently unfolding events. Reporting such events poses cognitive and linguistic challenges to children acquiring English, as evidenced by the fact that connectives such as *while* appear after markers of temporal sequence such as *then* or *next* and are not used productively until after age seven (Morgan, 2002). These challenges are attributed to the demands of having to keep the actions of more than one character in an event in mind, so younger children tend to focus on a single main character instead.

Adult signers may combine constructed action (CA) with lexical signs or CCs to represent the concurrent actions of more than one character. An adult BSL signer who retold the Frog Story described a boy falling from a tree while an owl emerged from it via the simultaneous production of a whole entity classifier for the boy and CA to represent the owl (Morgan, 2002). Children aged four to six exhibited no such combinations of CA and CCs. Children aged seven to ten still presented concurrent events sequentially by focusing on one character at a time, but their signing spaces started showing overlap. Older children aged 11—13 used sequential strategies like sandwiching one event between two mentions of another event. For instance, the boy in the Frog Story falls from a tree while his dog is being chased by bees; one child signed the boy's fall followed by the dog being chased, and then depicted the boy falling again. The children also used lexical means such as a verb of perception to encode temporal concurrence (e.g., SEE in "the dog sees the boy fall from a tree"). Importantly, none of the children in Morgan's study were reported to represent two characters' actions simultaneously by combining CA and classifier or lexical predicates.

Recent studies on the acquisition of a signed language by adult users of a spoken language (M2L2 learners, or "second modality, second language learners") show that adult L2 learners behave in similar ways to child L1 learners when it comes to the expression of simultaneous structure. Gulamani et al. (2022) looked at re-tellings of the Frog Story by 23 intermediate learners of BSL and noted that their use of CA was less frequent than CCs, one of the reasons being that it requires the coordinated use of more articulators. Gulamani et al. (2022) considered the articulations of the dominant hand, the non-dominant hand, the body, eyebrows, eyes, mouth, and head. The adult native participants in their study used five to seven articulators simultaneously substantially more frequently than the M2L2 learners, who used one to three articulators more frequently than the native signers. The authors suggest that the comparatively low information density in M2L2 narratives as compared to L1 narratives is due to the cognitive difficulties of (a) coordinating the articulation of several articulators and (b) keeping in working memory all relevant aspects of a scene while accessing a still developing language system.

## Acquisition of classifier constructions

One class of simultaneous expressions in sign languages that are enabled in part by the availability of two manual articulators are CCs. CCs form a system of schematic visual representations that are attested in most signed languages; they differ from lexical signs in that each of their formational components bears meaning. Importantly, the two hands may encode morpho-syntactically independent predicates (Zwitserlood, 2003) that in most accounts consist of a semantically light movement root and a classifier handshape (e.g., Benedicto and Brentari, 2004). Classifier handshapes in signed languages are morphemes denoting the semantic class, size, or form of the entity whose movement or location is being described, for example, a vehicle, airplane, small animal, or human (Supalla, 1982). CCs primarily denote spatial relations and the movement of entities, such that the handshape of each hand represents an entity involved in the event, the place of articulation in the sign space represents the location of an entity or the relative spatial orientation of entities with respect to each other, and the movements of the hands show the path and manner of motion of those entities (Zwitserlood, 2012).[5]

Classifiers and the constructions containing them are only mastered around age eight (Supalla, 1982; Schick, 1990a; Slobin et al., 2003).[6] This may be due to a number of independent properties of these constructions. First, representing more than one event participant simultaneously depends on the ability to use the two hands independently and may, as we have seen in Section "Acquisition of two-handed signs by deaf children," be motorically demanding. Second, these constructions allow the encoding of many event components simultaneously and may therefore place high cognitive demands on the child. We will first discuss the simultaneous encoding of Figure and Ground in bimanual CCs, which illustrates both of the above challenges, and then turn to the simultaneous expression of Manner and Path of movement as an example of the cognitive challenges of encoding multiple event components even in one-handed signs.

### Figure and Ground

One property of events that is often expressed simultaneously in CCs is the involvement of more than one entity. In locative expressions, this typically involves a Figure that either moves, or is located, with respect to a Ground entity. Figures are typically smaller and foregrounded while Grounds represent larger, backgrounded entities. According to Özyürek et al. (2010: 1120), the canonical structure of locative expressions across signed languages first introduces the Ground (Gr) via a lexical sign; that sign is followed by a CC that locates the Ground in the signing space. The non-dominant hand (ND) holds the final position of this CC while the dominant hand (D) introduces the Figure (Fig) via a lexical sign followed by a CC showing either the location or movement of the Figure in relation to the Ground. This structure is represented in (2), and

5 CCs may also encode how an object is handled or may give information about its visual characteristics, such as shape or size, but as most of the acquisition literature focuses on locative expressions, we will leave these aside for now.

6 Schick (1990b) reports that classifier handshapes are used correctly by age 4;5, while children as old as six to seven still have difficulty integrating spatial mapping into CCs.

has been attested in ASL, DSL, DGS, LSQ, BSL, Taiwan SL, and HKSL (Özyürek et al., 2010).

(2) ND: [Gr NP] [Locate Gr] - - - - - -hold- - - - - -
D: [Fig NP] [Locate Fig]

Supalla (1982) notes that Figure and Ground may be signed at the same time only if the signs representing them are one-handed. But if either the Figure or the Ground is represented by a two-handed sign, the motion verb encodes only the Figure, while the Ground is encoded by a preceding locative predicate. The grammatical possibilities for simultaneous expression are thus conditioned by the handedness of the constituent signs. It should be mentioned that, while the structure in (2) exhibits manual simultaneity in as much as Figure and Ground are signed (or at least held) at the same time, Özyürek et al. (2010) point out that simultaneity is not obligatory in encoding such locatives in Turkish Sign Language (TİD). They looked at descriptions of static spatial relations between two or more objects (e.g., boats on water, a painting on a wall), as well as motion descriptions of a Figure with respect to a Ground (e.g., a man walking toward a truck). Analyzing data on static spatial relations from six native TİD signers and on relative motion descriptions from four of the six signers, they found simultaneous Figure and Ground expression in just 1.4% of static spatial descriptions and in 20% of motion descriptions. Instead, signers often introduced and localized the Ground but did not hold it on the non-dominant hand when introducing the Figure, thereby requiring the addressee to keep the location of the Ground in mind. Using a similar study design, Perniss et al. (2015) also found a paucity of simultaneous Figure-Ground encoding in DGS, where only 7% of Figures were signed with respect to a Ground object held on the non-dominant hand. These findings raise questions about the frequency of simultaneous Figure-Ground constructions in the input to child learners of DGS and TİD, even those children who receive native input from deaf parents.

De Weerdt (2020) shows that simultaneous expression is influenced by whether Figure and Ground constitute new information or are already known to the interlocutors. Looking at production data from Finnish Sign Language, he notes that constructions with known Figures almost always triggered simultaneous descriptions (either of Figure and Ground or of Ground and a spatial adposition), while new Figures triggered simultaneous encoding in only 63% of descriptions. Perniss et al. (2015) claim that the simultaneous encoding of Figure and Ground marks non-default spatial relations between the two entities, for instance a boy standing on another boy's shoulders. De Weerdt assumes that, given the higher cognitive load of encoding Figure and Ground simultaneously, this construction is more likely to occur when interlocutors are already familiar with both referents.

## Acquisition of Figure and Ground

Children do not consistently include Ground information in their locative and motion CCs before age seven (Slobin et al., 2003 for ASL and NGT; Morgan et al., 2008 for BSL; Sümer, 2015 for TİD). Even in stative locative descriptions such as a ball sitting in a cup or a piece of paper lying under a bed, younger children will omit either Figure or Ground, with the Ground being omitted significantly more often (Sümer, 2015). Similar findings have been reported for HKSL (Tang et al., 2007), where learners were grouped by proficiency level rather than age or length of exposure.

Most studies report one common compensatory strategy: sequential predicates for Ground and Figure. An example given in Tang et al. (2007: 312) describes someone putting a hat on a bird's nest. While adults would use the non-dominant hand to represent the bird's nest by means of a located classifier, children first produced a one-handed sign to locate the bird's nest, then signed an existential predicate for the hat, and lastly used a handling classifier to show the placement of the hat in the same location where the nest had previously been located. These sequential strategies further varied by whether the child linked the separate predicates via location or not. Younger children tended to set up new event spaces in signing space for each predicate and would, for instance, place the bird's nest in a different location from the final (goal) location of the hat-moving predicate.

Children's frequent omission of Ground elements does not seem to be due to an inability to form a conceptual representation of Ground. Even children with low HKSL proficiency in Tang et al.'s (2007) study sometimes used the non-dominant hand to express the Ground. Alternatively, the HKSL participants sometimes treated their own body as a Ground on which a Figure would move or be located. Tang et al. (2007) offered the following explanation for the absence of simultaneous Figure-Ground encoding in children's productions: Descriptions of relative spatial location require the use of token space (Liddell, 1994). To use token space, children must abstract away from the signing space in front of them and project onto it an event space in which the articulators and the space itself stand in for something else; see Schick (1987), Morgan et al. (2008) for similar arguments based, respectively, on ASL and BSL acquisition data. In both ASL and HKSL, children make more errors with classifiers that use token space (entity classifiers) than with classifiers that use surrogate space (handling classifiers) (Tang et al., 2007; Morgan et al., 2008).

The cognitive load associated with this abstraction process may mean that something has to give elsewhere. A strategy for lowering cognitive load is to reduce the number of referents represented within one CC. Omitting the Ground appears to be the preferred means of achieving this. According to Sümer (2015), Ground objects are also less salient in dynamic motion events such as rolling a tomato up a hill, where the moving Figure draws attention away from the Ground.

## Emergent signed languages

How does the acquisition of Figure and Ground encoding in established signed languages compare to the emergence of such encoding in young languages? Research on forms of gestural communication that, unlike conventional signed languages, have not been transmitted from generation to generation within a stable signing community provides the opportunity to probe the conditions under which simultaneous vs. sequential structures emerge. For instance, Goldin-Meadow et al. (1996) asked hearing non-signing adults to describe motion events using gesture, both with and without concurrent speech. They found that when participants produced gestures concurrently with speech, those gestures typically encoded information holistically, for instance using a gesture for a round object (the Figure) and moving it along some path. By contrast, when the participants were asked to produce gestures without speech, they produced a sequence of discrete gestures for each element of the motion event, e.g., using a gesture for a round object followed by a gesture tracing its path. Goldin-Meadow et al. (1996) argue that segmentation begins to arise when the full burden of communication is shifted to the manual modality.

Moving up the scale of conventionalization, we can also examine the kinds of structure that develop when a deaf child who cannot access spoken language and has not been exposed to a conventional signed language generates a novel sign system and continues to use it over an extended period of time as his or her primary means of communication, i.e., "homesign" (Goldin-Meadow and Feldman, 1975). Homesign systems represent an intermediate stage between gesture and full-blown signed languages. Despite the fact that these children have no systematic input from a conventional language, they nonetheless seek to communicate with their family members. We can examine the kinds of structures that develop when an isolated deaf child generates a novel sign system and continues to use it over an extended period of time as his or her primary means of communication.

According to Goldin-Meadow et al. (1995), American homesigners reliably produce sequences of discrete gestures for Figure and Path. Zheng and Goldin-Meadow (2002: 54) also observe that American and Chinese child homesigners "often produced separate gestures for the nominal elements of a motion event" (i.e., the Figure and Ground). The authors do not specify whether these gestures are ever produced simultaneously. Gentner et al. (2013) report that young Turkish homesigners (age range 3;8—5;6) rarely encoded Figure and Ground simultaneously. In the majority of their pertinent utterances (21/33), the children omitted one of these elements. Of the minority of utterances in which both elements were represented (12/33), only two contained simultaneous signs representing Figure and Ground. Morford (2002) elicited narratives from two adolescent homesigners; while both consistently represented Figure, neither explicitly represented Ground in any of their utterances.

Preliminary data from Zinacantec Family Homesign (ZFHS), an emergent sign language developed by three, now-adult, deaf siblings and their extended family members in southern Mexico, shed some light on how Figure and Ground are encoded in an emergent signed language (German, 2022a,b; see also Haviland, 2020). Descriptions of 40 motion events that included a moving Figure and a stationary Ground were elicited from all seven fluent signers of ZFHS (three deaf and four hearing). The eldest signer Jane typically encodes Figure and Ground with a sequence of separate CCs. For instance, in **Figure 3** Jane describes a tricycle passing by a truck by first producing a CC for the Ground in the signing space in front of her, and then producing a second CC for the Figure, moving her hand past the location where the first CC was produced. By contrast, the later born ZFHS signers were generally more likely to encode Figure and Ground simultaneously. For instance, in **Figure 4**, the third deaf sibling Will describes the tricycle passing by the truck by first locating a CC for the truck in the signing space with his left hand. Then, using his right hand, he produces a CC for the truck by moving his right hand past his left hand, which maintains the CC for the hoop. The frequency of this simultaneous strategy increases as one moves from the oldest to the youngest signers.

## M2L2 acquisition

Signers who first learn a signed language as (young) adults come to the table with more developed cognitive and motor coordination skills than child learners. Nonetheless, their error patterns, especially in the acquisition of CCs, exhibit similarities to those of child learners. Boers-Visker (2021) looked at two-handed CCs in 14 M2L2 learners of NGT and found that learners produced omission errors well into the second year of their studies. In contrast to L1 learners, however, they sometimes self-corrected their productions, adding in the Ground on the non-dominant hand while holding the dominant hand in place. This points toward a cognitive demand as the cause of the omission errors rather than a purely motoric difficulty. Most of the NGT learners (9 of 14) also sometimes resorted to sequential constructions in place of simultaneous ones, for instance when describing a car and a truck standing next to each other.

Studies on M2L2 learners of NGT and Norwegian Sign Language (NTS) find that learners have difficulties in coordinating the use of their hands in relation to each other, especially across longer stretches of discourse. Ferrara and Nilsson (2017) report that NTS learners (approximately 1.5 years of study) sometimes crossed their arms in depicting an entity's movement, misjudging the hands' distance from each other; they would place entities higher in signing space than others that were at the same height in real space. Boers-Visker (2021) noted that learners of NGT had similar difficulties judging the size of the available space and would sometimes have the hands (almost) touching although the objects they represented further apart, or the hands would run out of signing

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FIGURE 3
Sequential encoding of Figure and Ground in Zinacantec Family Homesign. **(A)** CC for Ground. **(B)** CC for Figure.

FIGURE 4
Simultaneous encoding of Figure and Ground in Zinacantec Family Homesign. **(A)** CC for Ground. **(B)** Simultaneous CCs for Figure and Ground.

space (e.g., colliding with the torso). Again, the problem may be both cognitive and motoric, requiring the correct estimation of how much space is needed for a given representation and how the two hands need to be positioned toward each other in order to complete their movement unimpeded.

In summary, we see clear parallels between language acquisition and language emergence: Homesigners and young children acquiring an established signed language tend to omit either Figure or Ground in their depictions of motion events. Some adult M2L2 learners likewise omit one classifier in a CC. For children learning an established signed language such as TİD and HKSL, the evidence suggests that Ground is omitted more frequently than Figure. When they do represent both elements, they are typically encoded by separate signs at earlier stages, and simultaneously at later stages, after age seven (e.g., Sümer, 2015). Here, too, M2L2 learners sometimes choose sequential expressions. For ZFHS, the signing of Jane—the eldest signer—can be taken as representing an earlier stage in the emergence of the language; she tends to encode Ground and Figure using separate CCs. The signing of Will—the third-born deaf signer who acquired ZFHS from his older siblings—can be taken as representing a later stage of emergence. His encoding of Figure and Ground shows simultaneity in its linguistic organization.

## Path and Manner

Two additional properties of motion events are Path of motion and Manner of motion. Path refers to the trajectory along which the Figure moves (e.g., upward, downward, linear, circular, zig-zag shaped). Manner refers to the quality of the movement and is constrained by the characteristics of the moving entity (e.g., a ball may roll or bounce along a given path, while animate entities propel themselves in different ways, whether swimming, flying, running, jumping, etc.). In spoken languages, Path and Manner are typically expressed in separate lexical items (Talmy, 1985, 1991). For instance, in a "path-framed" language such as Spanish, Path is typically expressed in the main verb, while Manner is optionally expressed via a gerund or prepositional phrase, as in *la botella entró a la cueva flotando*, literally, "the bottle entered the cave floating" (Talmy, 1991: 488). In a "satellite-framed" language such as English, Path is typically encoded in a prepositional phrase while the main verb encodes Manner, as in "the bottle floated into the cave" (Talmy, 1991: 488). Path-Manner complementarity in verbal roots may fit into a larger picture of manner-result complementarity, a tendency for verbal roots to encode either the manner of an action or its result (as entailed by a directed path), but not both (Beavers et al., 2010).

### Established signed languages

Sign languages distinguish at least two types of Manner (Supalla, 1990): *Manner of locomotion* (e.g., 'walk', 'fly', or 'swim') and *Manner of motion along a path* (e.g., 'roll', 'bounce', or 'spiral'). In contrast to spoken languages, these two types of Manner are encoded differently in signed languages: Manner of locomotion is typically (but not always) encoded separately from Path[7], while Manner of motion along a path is almost always encoded simultaneously with Path (Supalla, 1982, 1990). For instance, to represent a person running up a hill in ASL, signers will first use a body classifier to represent the motion of the arms and hands while running, followed by a "person" classifier handshape ( ) moving upward (Manner of locomotion + Path). In contrast, to show a vehicle spiraling along a downward path in ASL, one would move the "vehicle" classifier handshape ( ) in a circular fashion while simultaneously moving it downward (Supalla, 1990: 129—133).

Path and Manner of locomotion are also sometimes expressed simultaneously within a single sign. Such signs may either be one- or two-handed: To represent a person walking (Manner of locomotion) upward (Path), a signer may wiggle the index and middle fingers of the upside-down V-hand ( ) while moving the entire hand upward. Taub and Galvan (2001) provide an example of a two-handed Manner of locomotion + Path expression in ASL, in which a person shuffling (Manner of locomotion) sideways along a window ledge (Path) can be represented by the two index fingers moving sideways in a slow and careful manner.

Most cases of simultaneous Manner of locomotion + Path encoding involve the upside-down V ( or "legs") classifier. In contrast to body-part classifiers, this classifier does not trigger the simultaneous use of constructed action. It shows Manner via the movement of index and middle fingers (walking, jumping, propelling the body forward in water) and it shows Path by displacement of the entire hand through space[8]. When looking at the acquisition of Manner + Path predicates, we will thus focus on Manners that can be expressed with the 1-( ) or V-( ) classifier, which allow for simultaneous encoding.

### Acquisition of established signed languages

Newport (1981, 1988) looks at the acquisition of complex motion verbs involving Path and Manner components in ASL and finds that children start producing mostly target-like simultaneous constructions by ages four to five. Younger children either omit meaning components of the complex motion predicate or they produce a sequential string of Manner and Path predicates. All of Newport's examples involve a straight or crooked -classifier ( or , respectively) for humans or animals moving on legs. For example, she reports the depiction of a Fisher-Price man walking across the top of a roof. Adult ASL signers report the event with a complex motion predicate featuring a linear path movement combined with the V-classifier, which encodes simultaneous 'walk' Manner. In contrast, a child aged 4;5 produced a horizontal Path movement followed by a Manner verb for 'walk' without a path component. Younger signers may sometimes produce simultaneous structures, but do not do so consistently. For

7 The reason for sequential encoding seems to lie in the form of manner of locomotion predicates. Most classifiers used to describe how humans or animals move are body-part classifiers, e.g., index fingers ( ) or B-hands ( ) representing legs, feet, or paws, or B-hands ( ) representing a swimmer's hands or a bird's wings. Body-part classifiers involve constructed action, whereby the signer's body comes to represent the body of the moving entity. Thus, to encode Path simultaneously, a signer would have to move her entire body along the path trajectory. This strategy is unlikely to be employed since the lower extremities are not typically considered to be phonologically significant in established signed languages, although it is attested in performative registers of signing (Quinto-Pozos and Mehta, 2010). Subsequently, Supalla's findings on sequential Manner of locomotion and Path encoding in ASL have been replicated for a number of signed languages: NGT (Slobin and Hoiting, 1994), Adamorobe SL (Nyst, 2007), Hong Kong SL (Tang and Yang, 2007), Argentinian SL, and Catalan SL (both Benedicto et al., 2008).

8 For a morphosyntactic analysis of the bi-eventive structure of the V-classifier in Russian SL, see Kimmelman et al. (2020). Tang and Yang (2007) note that the expressive potential of this classifier is somewhat limited, as it cannot represent manners of motion that saliently involve the hands. To represent 'marching' in HKSL, for instance, a body-part classifier predicate with arm movement has to precede the V-classifier showing Path and a 'marching' leg motion. Likewise, Benedicto et al. (2008) show an example from Argentinean SL of a horizontally oriented V-classifier following a body-part classifier for swimming. These examples show that signers add additional CCs in sequence because the V-classifier does not represent all the limbs involved in the manner of locomotion.

example, Slobin and Hoiting (1994) report on an ASL signer aged 3;8 who combines a walking Manner with a forward Path simultaneously.

Newport (1981) further reports two examples of a jumping or hopping Manner preceding a Path verb. In one case, a child (4;5) represented a hen jumping onto a barn roof with the crooked-V-classifier () performing an arc-shaped jumping predicate followed by an upward Path predicate. In the second example, this same child described a cow hopping up a hill with the V-classifier hopping in place followed by a forward movement with her whole body to show Path. These examples demonstrate that sequentialization errors appear even in one-handed CCs. Thus, factors other than motor control issues can push children toward sequentialization.

Separating the Path and Manner representations of a single motion event results in a less iconic (or "analog," in Newport's terms) event representation, but it may reflect how children acquire not only CCs but language in general. Newport suggests that children's perceptual and cognitive limitations (e.g., working memory limitations) lead to their perceiving and storing "excerpts" or components of complex constructions rather than the entire construction at once. For instance, a learner may perceive and store only the path of a complex movement (but not its manner) and therefore may store that path as a separate form. Selective perception and limited memory capacity may account for sequential productions of Path and Manner in younger children.

Singleton and Newport (2004) report on late learners of ASL exhibiting a similar tendency to encode each movement component via a separate sign. For instance, their late learners sometimes represented a car moving straight uphill as CAR MOVE STRAIGHT UPHILL, with separate signs for Motion, Path, and Direction. While children leave this analytical stage behind after roughly 5 years of ASL exposure, late learners may plateau in their acquisition, sometimes using CCs (e.g., WOMAN PASS DOG CL:$1_{palm\_down}$ + LINEAR 'a woman passes by a dog,' Singleton and Newport, 2004: 386) but sometimes using unanalyzed frozen forms.

## Emergent signed languages

Few studies have examined the expression of Manner and Path in gesture. Özyürek et al. (2015) reported that hearing non-signers typically combine Manner and Path information holistically in a single gesture, no matter whether that gesture is concurrent with speech or not.

In the expression of motion, homesign systems represent an intermediate stage between gesture and full-blown language. Like (silent) gesturers, homesigners do not consistently segment Manner and Path (Özyürek et al., 2015). They can refer to Manner and Path individually, suggesting that they can at least isolate the two elements. For instance, homesigners represent Path trajectories by moving their hands through space, often using unmarked handshapes (e.g., an open palm or the index finger ) that do not provide information about physical characteristics of the Figure (Zheng and Goldin-Meadow, 2002). Homesigners also produce signs that represent Manner, but not Path: e.g., to represent the "fluttering" manner of falling snowflakes, one homesigner wiggled his fingers while keeping the hand at a single point in space (Zheng and Goldin-Meadow, 2002). However, homesigners do not typically concatenate Manner and Path gestures into larger strings as child learners of an established sign language do. In Özyürek et al.'s study, Turkish homesigners described roughly 50% of events with salient Manner and Path components via conflated forms in which Manner and Path were expressed simultaneously; most remaining events were described with only a Path component: ∼35%; or only a Manner component: ∼10%. In one example from Zheng and Goldin-Meadow (2002), a homesigner represented a frog hopping forward with an up-and-down motion of the elbow joint combined with a forward movement at the shoulder joint. Homesigners differ from gesturers in that they sometimes add an additional Manner or Path gesture in sequence with a conflated Manner + Path gesture, which Özyürek et al. (2015) argue represents an initial step toward language-like segmentation that only occurs when the gesture system is maintained over an extended period of time.

Turning now to emergent signed languages, we first discuss Nicaraguan Sign Language (NSL). This language emerged when deaf children were brought together at a newly established school for the deaf in the late 1970s (Senghas and Coppola, 2001). The children in this first cohort were likely homesigners before they arrived at the school. However, their homesigns quickly developed into a new language, NSL, which was adopted by subsequent cohorts of children who enrolled at the school. Presumably this happened in part because the homesigners were now members of a community centered around the school.

Senghas et al. (2004) examined the segmentation of Manner and Path in the co-speech gestures of hearing Nicaraguan Spanish speakers (which may have served as input for NSL signers) and three successive cohorts of signers of Nicaraguan Sign Language. For instance, to represent a cartoon character rolling down the hill, participants could conflate Manner and Path in a single sign (ROLL + DOWN; see Figure 1A in Senghas et al., 2004), or they could sequence them, producing a separate sign for each (ROLL DOWN; Figure 1B in Senghas et al., 2004). These authors found that the hearing Nicaraguans conflated Manner and Path in 100% of their gestured expressions of motion, and the first cohort of NSL signers did so in 75% of their motion expressions. However, in the second and third cohorts of NSL signers, Manner and Path were conflated in only 32% and 38% of expressions, respectively; in the majority of expressions produced by these later cohorts, Manner and Path were encoded in separate signs. Thus, there was a clear increase in segmentation as NSL was passed down through successive cohorts. Senghas et al. (2004) interpret these cross-cohort differences as a transition from a holistic, gesture-like stage to a more language-like stage characterized by discrete, linear structure. This re-structuring of the grammar of NSL likely reflects the learning mechanisms that children bring to the task of language acquisition. According to Senghas et al., these include predispositions for analytical structure and linear sequencing that drive children to break down “bundles” of information (such as the holistic gestures of the hearing Nicaraguans) into their constituent parts, and then re-combine those parts in sequence. This proposal is consistent with Newport’s proposal as to why children learning ASL produced errors in which Manner and Path were separated.

Parallel results have been obtained for Zinacantec Family Homesign (ZFHS) (German, 2022a). The first-born deaf ZFHS signer, who developed the original homesign system from scratch, with access only to gestural input, typically conflates Manner and Path. By contrast, all later-born signers, who received signed input from older signers, strongly prefer to sequence those elements. Furthermore, there is a shift from whole-body signing in the first-born signer to primarily manual signing in the later-born signers. Specifically, the first-born signer often adopts the perspective of the Figure and uses CA to enact the entire motion event. Thus, in order to encode Path she must move her body through space. For instance, in **Figure 5**, the first-born ZFHS signer describes a cartoon character walking while carrying a heavy object. She encodes Manner and Path by literally walking her feet out from under the table a short distance. By contrast, the later-born signers use CA only to encode Manner and encode Path through a manual CC, much as signers of established languages do. For instance, in **Figure 6**, the third deaf sibling describes a cartoon character flying into an enclosure. He begins by representing the Manner (‘flying’) via CA (outstretched arms), followed by a two-handed CC that represents the Path of the Figure into the Ground (i.e., the path of the cartoon character into the enclosure). The differences between the first- and later-born ZFHS signers indicate that even input provided by other homesigners is sufficient to scaffold the emergence of Manner/Path sequencing. The results for ZFHS thus parallel those of Senghas et al. (2004) for NSL, but extend them to a social group of a much smaller scale, indicating that regardless of the size of the signing community, emergent signed languages undergo a shift from holistic enactment toward sequential, combinatorial representations.

FIGURE 5
The first-born ZFHS signer represents Manner and Path simultaneously via constructed action.

FIGURE 6
The third-born ZFHS signer represents Manner via constructed action, followed by Path via a classifier construction.

However, contrasting results have been obtained by Stoianov et al. (2022), who compare Cena, an emergent signed language of Brazil, with LIBRAS, the national sign language of Brazil. They elicited descriptions of motion events from 19 signers of each language using the Haifa clips, a set of video stimuli designed by Sandler et al. (2005). The authors found that signers of Cena and LIBRAS alike exhibited a strong preference for encoding Manner and Path of motion simultaneously. Thus, unlike the findings of Senghas et al. (2004) for NSL and those of German (2022a) for ZFHS, Stoianov et al. (2022) do not report a shift from simultaneous encoding to sequential encoding of Manner and Path as a signed language emerges. They argue that the shift from simultaneity to sequentiality is not universal among emergent languages, but is instead one of various possible outcomes depending on the sociolinguistic setting in which the language emerges. Specifically, they propose that a signed language that emerges when homesigners are brought together to form a signing community, such as NSL, will experience a shift from simultaneity to sequentiality, whereas a signed language arising in insular communities with a high rate of genetic deafness, such as Cena, will not. ZFHS fits neither of these profiles, yet seems to pattern like NSL in the encoding of Manner and Path. Further research is needed to determine the relationship between sociolinguistic setting and simultaneity in language emergence.

## Conclusion

In this paper, we have focused on simultaneity in two-handed expressions in signed languages. We have reviewed linguistic constraints on these expressions, discussed challenges that children and adult learners may face when acquiring them, and have synthesized the literature on the emergence of such expressions in young languages. Two hurdles that children may face in the acquisition of simultaneous expressions lie in the motor coordination of the two hands and in the cognitive load of representing many event components at the same time in an abstract space.

The literature on bimanual coordination in children suggests that they may struggle with inhibiting mirror movements in certain non-linguistic tasks requiring use of the non-dominant hand until ages eight to nine. In signed languages, Figure-Ground constructions and the use of discourse buoys require that the non-dominant hand be held in a particular configuration and in a particular location. This requires the suppression of any mirroring of the dominant hand. Logically, motor coordination difficulties could thus contribute to the late development of both structures.

Motoric complexity in children's production of two-handed expressions is often reduced through the omission of information that would typically be encoded on the non-dominant hand. Thus, the Ground in Figure-Ground constructions and the usages of the non-dominant hand that maintain topics in narratives are often omitted. Even adults in TİD and DGS typically opt for non-simultaneous expressions of Ground and Figure. The timelines of children's mastery of the inhibition of mirror movements and of signing children's consistent inclusion of Ground line up: Both are mastered around age eight, suggesting that motor coordination may have some role in the late emergence of Figure-Ground constructions. However, we have too little direct evidence on how motoric complexity affects the development of two-handed sign forms, even of very young children's acquisition of two-handed monomorphemic signs. A recommendation for future studies is this: independent measures of motor control skills in children would inform us as to whether motor control issues are indeed a limiting factor in children's acquisition of two-handed constructions, including CCs and narratives.

Motor coordination is clearly not the only obstacle children have to overcome in producing simultaneous constructions. Even adult M2L2 learners, whose motor coordination skills are arguably more advanced than those of child learners, still struggle with encoding the many simultaneous components of a narrative via multiple articulators, and they sometimes omit classifiers in Figure-Ground CCs. Some constraints on children's use of two-handed expressions seem to be independent of modality: for example, effective topic management across a discourse or narrative emerges around the same time in spoken and signed languages. In signed languages, weak-hand holds for topic maintenance and topic chaining start being used consistently around the same age as other narrative and discourse-structuring devices. More crucially, there are constraints on children's use of simultaneously organized linguistic constructions even in expressions that are one-handed in signed languages. In acquiring one-handed CCs in which the language allows the simultaneous encoding of both the Manner and Path of a motion event, children separate them out before age five. They employ sequential encoding even at the expense of the iconicity that the visual-gestural modality allows. Moreover, our review has raised the possibility that the input with respect to two-handed Figure-Ground CCs might be less rich than we might have expected. Clearly, unexpected sequential constructions in children's acquisition of signed languages are not just a response to the problems of coordinating linguistic expression across the two hands.

The cognitive load on the child likely plays a role here: Encoding many event components at the same time (whether they be the entities involved in the event or motion components such as Manner and Path) is cognitively demanding. De Weerdt (2020) argues that, even in adult signers, having two referents activated at the same time is demanding and therefore occurs more frequently if both referents are already known to the interlocutors. Children avoid layering of simultaneously occurring event components by either omitting some (e.g., the Ground in Figure-Ground constructions), or they express each component sequentially. In addition to tracking various event components, children also need to learn how to use the space in front of them as an abstract canvas onto which referents and their actions can be projected. Adult M2L2 learners, who struggle with the additional cognitive load of accessing a still developing language system, reduce the demands of encoding several event components simultaneously in similar ways as child learners: by omitting a classifier in a two-handed CC or by choosing a sequential expression.

When we compare children's acquisition of simultaneous structures with how these structures develop in emerging sign languages, interesting parallels emerge, but there are also differences. With respect to Figure-Ground constructions, child learners tend to omit the Ground element while signers of emergent languages produce the two elements sequentially. In both cases, the result is an avoidance of simultaneity where it would be expected among adult signers of established languages (although recall that simultaneous expression of Figure and Ground appears to be less frequent in some established sign languages than we might have anticipated). With respect to Manner-Path constructions, the initial stages of acquisition and emergence differ, but their later stages are similar. While there is little data on whether child learners produce holistic forms initially, the earliest cohorts of signers of emergent languages rely primarily on holistic forms in which Manner and Path are produced simultaneously. In later stages of both acquisition and emergence (but see our earlier discussion of Cena), there is a tendency to produce Manner and Path sequentially. One explanation for this trajectory is that sequentiality and omission first arise when learners start breaking holistic signals up into their component parts. Children have to learn that CCs have sublexical structure; signers of emergent signed languages develop morphological structure by segmenting the linguistic expression of complex events into separate, sequential morphemes. Later, child learners start making full use of the potential of visual-gestural languages to layer information simultaneously and to thereby represent complex events iconically.

In language emergence, our review has revealed opposite patterns for Manner-Path (simultaneous then sequential) and Figure-Ground (sequential then simultaneous). This suggests that bimanual coordination could impact the emergence of simultaneously organized constructions. Representing Manner and Path simultaneously does not necessarily involve two hands, so—on this account—signers exploit simultaneity from the earliest stages of language emergence. By contrast, representing Figure and Ground simultaneously does indeed require that the signer coordinate the movements of the two hands. Thus, as in acquisition, motor coordination factors could form part of an explanation for why Figure and Ground are frequently expressed sequentially at the earliest stages of emergence. Much more research on the structure and acquisition of established signed languages and on the emergence of new signed languages is needed to understand the path toward simultaneity in visual-gestural languages.

## Ethics statement

Written permission from the copyright holder was obtained to reproduce the images in **Figures 1**, **2**. AG's research on ZFHS has been approved by the Institutional Review Board of the University of Texas at Austin, which waived the requirement for written informed consent based on the participants' non-literacy and their cultural concerns about signing documents. Informed consent was obtained orally, including participants' permission to publish their images (**Figures 3–6**) in research publications.

## Author contributions

CL wrote the parts of section "Introduction," all of section "Acquisition of narrative and discourse functions of simultaneity," and the first draft of section "Conclusion." CL and AG wrote the section "Acquisition of classifier constructions." AG wrote the subsections on emergent signed languages. RM wrote the section "Simultaneity in the lexicon: The two hands." All authors contributed to the conception and structure of this manuscript and contributed to revisions of the manuscript, read drafts, and approved the submitted version.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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# References


Abner, N. (2019). "Determiner phrases: theoretical perspectives," in *The Routledge Handbook of Theoretical and Experimental Sign Language Research*, eds J. Quer, R. Pfau, and A. Herrmann (Abingdon NY: Routledge), 213–226. doi: 10.4324/9781315754499-10

Anderson, D., and Reilly, J. (2002). The MacArthur communicative development inventory: normative data for American sign language. *J. Deaf Stud. Deaf Educ.* 7, 83–106. doi: 10.1093/deafed/7.2.83

Aronoff, M., Meir, I., and Sandler, W. (2005). The paradox of sign language morphology. *Language* 81, 301–344. doi: 10.1353/lan.2005.0043

Battison, R. (1978). *Lexical borrowing in American Sign Language.* Silver Spring, MD: Linstok Press.

Beavers, J., Levin, B., and Tham, S. W. (2010). The typology of motion events revisited. *J. Linguistics* 46, 331–337. doi: 10.1017/S0022226709990272

Benedicto, E., and Brentari, D. (2004). Where did all the arguments go?: argument-changing properties of classifiers in ASL. *Nat. Lang. Linguistic Theory* 22, 743–810. doi: 10.1007/s11049-003-4698-2

Benedicto, E., Cvejanov, S., and Quer, J. (2008). "The morphosyntax of verbs of motion in serial constructions: a crosslinguistic study in three signed languages," in *Signs of the Time: Selected Papers from TISLR 2004*, ed. J. Quer (Hamburg: Signum Verlag), 111–132.

Boers-Visker, E. (2021). On the acquisition of complex classifier constructions by L2 learners of a sign language. *Lang. Teach. Res.* doi: 10.1177/1362168821990968 [Epub ahead of print].

Börstell, C., Lepic, R., and Belsitzman, G. (2016). Articulatory plurality is a property of lexical plurals in sign language. *Lingvisticae Invest.* 39, 391–407. doi: 10.1075/li.39.2.10bor

Brakke, K., and Pacheco, M. M. (2019). The development of bimanual coordination across childhood. *Monographs Soc. Res. Child Dev.* 84, 7–147. doi: 10.1111/mono.12405

Caballero, G., and German, A. (2021). Grammatical tone patterns in Choguita Rarámuri (Tarahumara). *Int. J. Am. Linguist.* 87, 149–178. doi: 10.1086/712980

Caselli, N., Sehyr, Z. S., Cohen-Goldberg, A. M., and Emmorey, K. (2017). ASL-LEX: a lexical database of American sign language. *Behav. Res. Methods* 49, 784–801. doi: 10.3758/s13428-016-0742-0

Cheek, A., Cormier, K., Repp, A., and Meier, R. P. (2001). Prelinguistic gesture predicts mastery and error in the production of early signs. *Language* 77, 292–323. doi: 10.1353/lan.2001.0072

Clark, E. V. (2016). *First Language Acquisition*. Cambridge: Cambridge University Press. doi: 10.1017/CBO9781316534175

Connolly, K., and Stratton, P. (1968). Developmental changes in associated movements. *Dev. Med. Child Neurol.* 10, 49–56. doi: 10.1111/j.1469-8749.1968.tb02837.x

Cruz, E. (2011). *Phonology, Tone, and the Functions of Tone in San Juan Quiahije Chatino*. dissertation, Austin, TX: University of Texas at Austin.

De Weerdt, D. (2020). Figure-ground spatial relationships in finnish sign language discourse. *Open Linguistics* 6, 723–746. doi: 10.1515/opli-2020-0041

Eccarius, P., and Brentari, D. (2007). Symmetry and dominance: a cross-linguistic study of signs and classifier constructions. *Lingua* 117, 1169–1201. doi: 10.1016/j.lingua.2005.04.006

Engberg-Pedersen, E. (1993). *Space in Danish Sign Language: The Semantics and Morphosyntax of the Use of Space in a Visual Language*. Washington, DC: Gallaudet University Press.

Engberg-Pedersen, E. (1994). "Some simultaneous constructions in Danish Sign Language," in *Word-order Issues in Sign Language. Working Papers*, eds M. Brennan and G. H. Turner (Durham: International Sign Linguistics Association), 73–88.

Fagard, J., Swinnen, S. P., Heuer, H., Maisson, J., and Cassaer, P. (1994). "Manual strategies and interlimb coordination during reaching, grasping, and manipulating during the first year of life," in *Interlimb Coordination: Neural, Dynamical, and Cognitive Constraints*, (San Diego, CA: Academic Press), 442–460. doi: 10.1016/B978-0-12-679270-6.50026-7

Ferrara, L., and Nilsson, A. L. (2017). Describing spatial layouts as an L2M2 signed language learner. *Sign Lang. Linguist.* 20, 1–26. doi: 10.1075/sll.20.1.01fer

Friedman, L. A. (1975). Space, time, and person reference in American Sign Language. *Language* 51, 940–961. doi: 10.2307/412702

Gee, J. P., and Shepard-Kegl, J. A. (1983). Narrative-story structure, pausing, and american sign language. *Discourse Process.* 6, 243–258.

Geffen, G. M., Jones, D. L., and Geffen, L. B. (1994). Interhemispheric control of manual motor activity. *Behav. Brain Res.* 64, 131–140. doi: 10.1016/0166-4328(94)90125-2

Gentner, D., Ozyürek, A., Gürcanli, O., and Goldin-Meadow, S. (2013). Spatial language facilitates spatial cognition: Evidence from children who lack language input. *Cognition* 127, 318–330. doi: 10.1016/j.cognition.2013.01.003

German, A. (2022a). "The emergence of combinatorial structure in Zinacantec Family Homesign," in *Paper presentation at the 96th annual meeting of the Linguistics Society of America, January 6–9*, Washington, DC. doi: 10.13140/RG.2.2.24768.20485

German, A. (2022b). "Evidence of an emergent classifier system in Zinacantec Family Homesign," in *Paper presentation at conference on Cultural and Cognitive Influences on Language Emergence*, May 25–27 (Virtual conference).

Goldin-Meadow, S., and Feldman, H. (1975). The creation of a communication system? a study of deaf children of hearing parents. *Sign Lang. Stud.* 8, 225–234. doi: 10.1353/sls.1975.0011

Goldin-Meadow, S., McNeill, D., and Singleton, J. (1996). Silence is liberating: removing the handcuffs on grammatical expression in the manual modality. *Psychol. Rev.* 103, 34–55. doi: 10.1037/0033-295X.103.1.34

Goldin-Meadow, S., Mylander, C., and Butcher, C. (1995). The resilience of combinatorial structure at the word level: morphology in self-styled gesture systems. *Cognition* 56, 192–262. doi: 10.1016/0010-0277(95)00662-I

Gulamani, S., Marshall, C., and Morgan, G. (2022). The challenges of viewpoint-taking when learning a sign language: data from the 'frog story' in British Sign Language. *Second Lang. Res.* 38, 55–87. doi: 10.1177/0267658320906855

Haviland, J. B. (2020). "Zinacantec family homesign (or 'Z')," in *Emerging Sign Languages of the Americas*, eds O. LeGuen, J. Safar, and M. Coppola (Berlin: DeGruyter, Ishara Press), 393–400. doi: 10.1515/9781501504884-009

Kimmelman, V., Pfau, R., and Aboh, E. O. (2020). Argument structure of classifier predicates in russian sign language. *Nat. Lang. Linguist. Theory* 38, 539–579. doi: 10.1007/s11049-019-09448-9

Klima, E., and Bellugi, U. (1979). *The Signs of Language*. Cambridge, MA: Harvard University Press.

Liddell, S. (1994). "Tokens and surrogates," in *Perspectives on Sign Language Structure: Papers from the 5th International Symposium on Sign Language Research*, Vol. 1, eds I. Ahlgren, B. Bergman, and M. Brennan (Durham: International Sign Linguistics Association), 105–119.

Liddell, S. (2003). *Grammar, Gesture and Meaning in American Sign Language*. Cambridge: Cambridge University Press. doi: 10.1017/CBO9780511615054

Lillo-Martin, D., and Meier, R. P. (2011). On the linguistic status of 'agreement' in sign languages. *Theor. Linguist.* 37, 95–141. doi: 10.1515/thli.2011.009

Marentette, P. F., and Mayberry, R. I. (2000). "Principles for an emerging phonological system: a case study of early ASL acquisition," in *Language Acquisition by Eye*, eds C. Chamberlain, J. P. Morford, and R. I. Mayberry (Mahwah, NJ: Lawrence Erlbaum Associates), 71–90.

Meier, R. P. (1993). "A psycholinguistic perspective on phonological segmentation in sign and speech," in *Phonetics and Phonology: Current Issues in American Sign Language Phonology*, ed. G. R. Coulter (San Diego, CA: Academic Press), 169–188. doi: 10.1016/B978-0-12-193270-1.50013-3

Meier, R. P. (2002). "Why different, why the same? explaining effects and non-effects of modality upon linguistic structure in sign and speech," in *Modality and Structure in Signed and Spoken Languages*, eds R. P. Meier, K. Cormier, and D. Quinto-Pozos (Cambridge: Cambridge University Press), 1–25. doi: 10.1017/CBO9780511486777.001

Miller, C. (1994). "Simultaneous constructions in Quebec Sign Language," in *Proceedings of the Perspectives on Sign Language Structure: Papers from the 5th International Symposium on Sign Language Research*, eds I. Ahlgren, B. Bergman, and M. Brennan (Durham: International Sign Linguistics Association), 89–112.

Morford, J. P. (2002). The expression of motion events homesign. *Sign Lang. Linguist.* 5, 55–71. doi: 10.1075/sll.5.1.05mor

Morgan, G. (2002). Children's encoding of simultaneity in British Sign Language narratives. *Sign Lang. Linguist.* 5, 131–165. doi: 10.1075/sll.5.2.04mor

Morgan, G., Herman, R., Barriere, I., and Woll, B. (2008). The onset and mastery of spatial language in children acquiring British Sign Language. *Cogn. Dev.* 23, 1–19. doi: 10.1016/j.cogdev.2007.09.003

Newport, E. L. (1981). "Constraints on structure: evidence from American Sign Language and language learning," in *Minnesota Symposium on Child Psychology*, ed. W. A. Collins (Hillsdale, NJ: Erlbaum), 93–124.

Newport, E. L. (1988). Constraints on learning and their role in language acquisition: studies of the acquisition of American Sign Language. *Lang. Sci.* 10, 147–172. doi: 10.1016/0388-0001(88)90010-1

Newport, E. L., and Meier, R. P. (1985). "The acquisition of American Sign Language," in *The Crosslinguistic Study of Language Acquisition. The Data*, ed. D. I. Slobin (Hillsdale, NJ: Lawrence Erlbaum Associates), 881–938. doi: 10.4324/9781315802541-12

Nyst, V. A. S. (2007). *A Descriptive Analysis of Adamorobe Sign Language (Ghana)*. dissertation, Amsterdam: University of Amsterdam LOT dissertation series.

Odden, D. (1995). "Tone: African languages," in *The Handbook of Phonological Theory*, ed. J. Goldsmith (Oxford: Blackwell), 444–475.

Özyürek, A., Furman, R., and Goldin-Meadow, S. (2015). On the way to language: event segmentation in homesign and gesture. *J. Child Lang.* 42, 64–94. doi: 10.1017/S0305000913000512

Özyürek, A., Zwitserlood, I., and Perniss, P. (2010). Locative expressions in signed languages: a view from Turkish Sign Language (TİD). *Linguistics* 48, 1111–1145. doi: 10.1515/ling.2010.036

Padden, C. A., and Perlmutter, D. M. (1987). American Sign Language and the architecture of phonological theory. *Nat. Lang. Linguistic Theory* 5, 335–375. doi: 10.1007/BF00134553

Perniss, P., Zwitserlood, I., and Özyürek, A. (2015). Does space structure spatial language? a comparison of spatial expression across sign languages. *Language* 91, 611–641. doi: 10.1353/lan.2015.0041

Pfau, R., and Steinbach, M. (2006). Pluralization in sign and in speech: a cross-modal typological study. *Linguistic Typol.* 10, 135–182. doi: 10.1515/LINGTY.2006.006

Pinker, S., and Bloom, P. (1990). Natural language and natural selection. *Behav. Brain Sci.* 13, 707–784. doi: 10.1017/S0140525X00081061

Prinz, P. M., and Prinz, E. A. (1985). If only you could hear what I see: discourse development in sign language. *Discourse Proc.* 8, 1–19. doi: 10.1080/01638538509544605

Quinto-Pozos, D., and Mehta, S. (2010). Register variation in mimetic gestural complements to signed language. *J. Pragmatics* 42, 557–584. doi: 10.1016/j.pragma.2009.08.004

Sandler, W., and Lillo-Martin, D. (2006). *Sign Language and Linguistic Universals*. Cambridge: Cambridge University Press. doi: 10.1017/CBO9781139163910

Sandler, W., Meir, I., Padden, C., and Aronoff, M. (2005). The emergence of grammar: systematic structure in a new language. *Proc. Natl. Acad. Sci. U S A.* 102, 2661–2665. doi: 10.1073/pnas.0405448102

Schembri, A. (2003). "Rethinking 'classifiers' in signed languages," in *Perspectives on Classifier Constructions in Sign Languages*, ed. K. Emmorey (Mawhah, NJ: Lawrence Earlbaum Associates), 13–44.

Schick, B. (1987). *The Acquisition of Classifier Predicates in American Sign Language*. dissertation, West Lafayette, IN: Purdue University.

Schick, B. (1990a). Classifier predicates in American Sign Language. *Int. J. Sign Linguist.* 1, 15–40.

Schick, B. (1990b). "The effects of morphosyntactic structure on the acquisition of classifier predicates in ASL," in *Sign Language Research: Theoretical Issues*, ed. C. Lucas (Washington, DC: Gallaudet University Press), 358–374.

Scroggs, C. (1981). The use of gesturing and pantomiming: the language of a nine-year-old deaf boy. *Sign Lang. Stud.* 30, 61–77. doi: 10.1353/sls.1981.0011

Sehyr, Z. S., Caselli, N., Cohen-Goldberg, A. M., and Emmorey, K. (2021). The ASL-LEX 2.0 project: a database of lexical and phonological properties for 2,723 signs in American Sign Language. *J. Deaf Stud. Deaf Educ.* 26, 263–277. doi: 10.1093/deafed/enaa038

Senghas, A., and Coppola, M. (2001). Children creating language: How nicaraguan sign language acquired a spatial grammar. *Psychol. Sci.* 12, 323–328. doi: 10.1111/1467-9280.00359

Senghas, A., Kita, S., and Özyürek, A. (2004). Children creating core properties of language: evidence from an emerging sign language in Nicaragua. *Science* 305, 1779–1782. doi: 10.1126/science.1100199

Shield, A., Igel, M., Randall, K., and Meier, R. P. (2020). The source of palm orientation errors in the signing of children with ASD: imitative, motoric, or both? *Brain Sci.* 10:268. doi: 10.3390/brainsci10050268

Siedlecki, T., and Bonvillian, J. D. (1993). Phonological deletion revisited: errors in young children's two-handed signs. *Sign Lang. Stud.* 80, 223–242. doi: 10.1353/sls.1993.0000

Singleton, J., and Newport, E. (2004). When learners surpass their models: the acquisition of American Sign Language from inconsistent input. *Cogn. Psychol.* 49, 370–407. doi: 10.1016/j.cogpsych.2004.05.001

Slobin, D., Hoiting, N., Kuntze, M., Lindert, R., Weinberg, A., Pyers, J., et al. (2003). "A cognitive/functional perspective on the acquisition of classifiers," in *Perspectives on Classifier Constructions in Sign Languages*, ed. K. Emmorey (Mahwah, NJ: Lawrence Erlbaum Associates), 271–296.

Slobin, D. I., and Hoiting, N. (1994). "Reference to movement in spoken and signed languages: Typological considerations," in *Proceedings of the annual meeting of the Berkeley linguistics society,* Vol. 20, 487–505.

Stoianov, D., da Silva, D. S., Freitas, J. C. N., Almeida-Silva, A., and Nevins, A. (2022). Comparing iconicity trade-offs in Cena and Libras during a sign language production task. *Languages* 7:98. doi: 10.3390/languages7020098

Stokoe, W., Casterline, D., and Croneberg, C. (1965). *A dictionary of american sign language on linguistic principles.* Silver Spring, MD: Lanstok Press.

Sümer, B. (2015). *Acquisition of Spatial Language by Signing and Speaking Children: A Comparison of Turkish Sign Language (TID) and Turkish*. dissertation, Nijmegen: Radboud University.

Supalla, T. (1982). *Structure and Acquisition of Verbs of Motion and Location in American Sign Language*. dissertation, San Diego CA: University of California.

Supalla, T. (1990). "Serial verbs of motion in ASL," in *Theoretical Issues in Sign Language Research: Linguistics*, eds S. Fischer and P. Siple (Chicago, IL: University of Chicago Press), 127–152.

Supalla, T., and Newport, E. L. (1978). "How many seats in a chair? The derivation of nouns and verbs in American Sign Language," in *Understanding Language through Sign Language Research*, ed. P. Siple (New York, NY: Academic Press), 91–132.

Szameitat, S. (2009). *Phonological Processes in Children's Acquisition of American Sign Language*. Master's thesis, Boulder, CO: University of Colorado.

Talmy, L. (1985). "Lexicalization patterns: Semantic structure in lexical forms," in *Language Typology and Syntactic Description: Grammatical Categories and the Lexicon*, ed. T. Shopen (Cambridge: Cambridge University Press), 57–194.

Talmy, L. (1991). "Path to realization: a typology of event conflation," in *Proceedings of the 17th Annual Meeting of the Berkeley Linguistics Society*, (Berkeley, CA: Berkeley Linguistics Society), 480–519. doi: 10.3765/bls.v17i0.1620

Tang, G., Sze, F., and Lam, S. (2007). "Acquisition of simultaneous constructions by deaf children of hong kong sign language," in *Simultaneity in sign language: Form and function,* eds M. Vermeerbergen, L. Leeson, and O. Crasborn (Amsterdam: Benjamins).

Tang, G., and Yang, G. (2007). Events of motion and causation in Hong Kong Sign Language. *Lingua* 117, 1216–1257. doi: 10.1016/j.lingua.2006.01.007

Taub, S., and Galvan, D. (2001). Patterns of encoding in ASL motion descriptions. *Sign Lang. Stud.* 1, 175–200. doi: 10.1353/sls.2001.0006

Tkachman, O., Purnomo, G., and Gick, B. (2021). Repetition patterns in two-handed balanced signs: vestigial locomotor central pattern generators shape sign language phonetics and phonology. *Front. Commun.* 5:612973. doi: 10.3389/fcomm.2020.612973

Valli, C., and Lucas, C. (1995). *Linguistics of American Sign Language: A Resource Text for ASL Users*. Washington, DC: Gallaudet University Press.

van Boven, C. (2021). Phonological restrictions on nominal pluralization in Sign Language of the Netherlands: evidence from corpus and elicited data. *Folia Linguistica* 55, 313–359. doi: 10.1515/flin-2021-2039

Vermeerbergen, M., Leeson, L., and Crasborn, O. (eds) (2007). *Simultaneity in Sign Language: Form and Function*. Amsterdam: John Benjamins. doi: 10.1075/cilt.281

Wolff, P. H., Gunnoe, C. E., and Cohen, C. (1983). Associated movements as a measure of developmental age. *Dev. Med. Child Neurol.* 25, 417–429. doi: 10.1111/j.1469-8749.1983.tb13786.x

Wolff, P. H., Kotwica, K., and Obregon, M. (1998). The development of interlimb coordination during bimanual finger tapping. *Int. J. Neurosci.* 93, 7–27. doi: 10.3109/00207459808986408

Yakovlev, P., and Lecours, A. R. (1967). "Myelogenetic cycles in regional maturation of the nervous system in man," in *Regional Development of the Brain in Early Life*, ed. A. Minkowski (London: Blackwell), 3–65.

Zheng, M., and Goldin-Meadow, S. (2002). Thought before language: how deaf and hearing children express motion events across cultures. *Cognition* 85, 145–175. doi: 10.1016/S0010-0277(02)00105-1

Zwitserlood, I. (2003). *Classifying Hand Configuration in Nederlandse Gebarentaal*. dissertation, Utrecht: University of Utrecht.

Zwitserlood, I. (2012). "Classifiers," in *Sign Language: An International Handbook*, eds R. Pfau, M. Steinbach, and B. Woll (Berlin: De Gruyter Mouton), 158–185. doi: 10.1515/9783110261325.158

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# Second language learning of depiction in a different modality: The case of sign language acquisition

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This study investigated the acquisition of depicting signs (DS) among students learning a signed language as their second-modality and second-language (M2L2) language. Depicting signs, broadly described, illustrate actions and states. This study sample includes 75 M2L2 students who were recruited from college-level American Sign Language (ASL) courses who watched and described three short clips from *Canary Row* the best they could in ASL. Four types of DS were coded in the students' videorecorded retellings: (1) entity depicting signs (EDS); (2) body part depicting signs (BPDS); (3) handling depicting signs (HDS); and (4) size-and-shape specifiers (SASS). Results revealed that SASS and HDS increase in instances as students advance in their ASL learning and comprehension. However, EDS expressions did not have a relationship with their ASL comprehension. ASL 2 students produced less DS than the ASL 1 students but did not differ from the ASL 3+ students. There were no differences in instances of BPDS among the three groups of L2 learners although their ability to produce BPDS was correlated with their ASL comprehension. This study is the first to systematically elicit depicting signs from M2L2 learners in a narrative context. The results have important implications for the field of sign language pedagogy and instruction. Future research, particularly cross-sectional and/or longitudinal studies, is needed to explore the trajectory of the acquisition of DS and identify evidence-based pedagogical approaches for teaching depicting signs to M2L2 students.

KEYWORDS

**depiction, sign language, second language acquisition, second modality, language learning**

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# Introduction

While teaching signed language is increasing in popularity worldwide, very little research has been done related to how hearing individuals learn sign languages on a global scale. Hearing second language (L2) learners are not only learning a new language, but also a new visual-gestural modality (M2) of communication (Chen Pichler and Koulidobrova, 2016). Little is known about how hearing students learn American Sign Language (ASL) as a second language in a second modality. Rosen (2020) discussed how practitioners in the field "often revert to their own understanding of what language is, how to teach it, how learners learn, and how to assess learners' language knowledge and skills" (p. 17). This study builds on Clark's (2016) theoretical framework of depiction as basic tools to relay information about people, places, things, and events.

In this article, we describe how M2L2 learners acquire skills related to depicting signs in the visual-gestural modality as observed in a cross-sectional study. In literature, some sign language researchers use the word *classifiers*. In this paper, we will refer *classifiers* to *depicting signs*. The use of depicting signs by deaf signers has been well-documented across a variety of signed languages and ages; deaf children as young as 2–3 years of age (Schick, 1987; Slobin et al., 2003) can produce depicting handshapes that are a part of depicting signs. The present study focused on four different depicting signs: (1) Entity depicting signs; (2) Body part depicting signs; (3) Handling depicting signs; and (4) Size-and-shape specifiers (SASS). The study provides insight into the difficulties they encounter and typical learner behaviors.

Some of the subjects in this study took ASL classes. Those subjects who took ASL classes at the university were exposed to the same curriculum, an ASL e-curriculum, that was based on the American Council of Teaching Foreign Languages (ACTFL)'s national standards. ACTFL published ASL national standards (Ashton et al., 2014). The philosophy behind ACTFL foreign language classes is based on a "spiral" concept: everything should be introduced at the beginning level and continue to be taught in more advanced classes. For example, basic and static depicting handshapes that do not require much movement are introduced in beginning ASL classes. More complex levels of depicting handshapes and signs including entity that entails movement are introduced later in more advanced ASL classes. The ASL program for foreign/modern language credit has ∼1,000 students every year. ASL classes enroll up to 20 students in each class. Approximately ten faculty members teach ASL classes for foreign/modern credits. Most of these faculty members are either lecturers (non-tenure track faculty) or adjunct faculty members. Tenure track and tenured faculty are reserved for matriculated interpreting classes with degree-seeking students. We recognize the variations regarding teaching experience and qualifications.

# Background

## Second language and second modality learners

Despite the growth of interest in researching the fields of sign second language acquisition (SSLA) and sign language pedagogy in the past 30 or so years, there is not much research in SSLA (see Chen Pichler and Koulidobrova, 2016; Boers-Visker and Pfau, 2020; Rosen, 2020; Schönström, 2021). While spoken languages are oral-aural, signed languages are gestural-visual. Here we discuss the second modality of second language learners whose first modality (M1) is a spoken language (based on sound and use of their mouth and tongue) and whose second modality (M2) is a signed language (based on vision and use of body, hands, arms, head, and facial expressions). Most foreign language students learn their second language in their first modality (M1L2) but here we focus on those learning a second language in their second modality (M2L2) (Hill et al., 2018). There are many variables to consider related to L2 acquisition compared to first language (L1) acquisition. Learners acquiring their second language come from different native language backgrounds and are at different stages of life (e.g., childhood L2 and adult L2). In this study we focus primarily on adult learners who take ASL classes as part of their foreign/modern language credit requirements at a private university in the Northeastern part of the United States. "Extending L2 investigations to sign language introduces yet another important variable, that of modality…In view of these potential modality effects, it is quite plausible that learning a second language in a different modality from one's first language may present possibilities, difficulties, and therefore development patterns that do not occur for L2 learning in the same modality as one's L1" (Chen Pichler and Koulidobrova, 2016, p. 219).

Literature on spoken L2 acquisition focuses a great deal on linguistic transfer. Some common research questions related to M2L2 are whether M2L2 learners' linguistic features transfer from M1 to M2 and L1 to L2. If yes, which linguistic features tend to transfer? Do these learners' patterns transfer to M2L2 because of their early mastery of a spoken language or because of their use of gestures? Language transfer has been documented for L2 learners at all grammatical levels. For example, L2 learners may apply their word order patterns in their L2 that follow the word order in their first language: an ASL student whose first language is English might attempt to sign ASL or use gestures using English word order and syntactic rules. Some studies show that for M2L2 learners, experience with gestures including co-speech gestures, facial expressions and other non-manual cues could transfer into L2 learners' attempt to express in sign language (see Taub et al., 2008; Chen Pichler, 2009, 2011; Brentari et al., 2012; Ortega, 2013; Ortega and Morgan, 2015). More research is needed to explore the extent of potentially transferable features especially in M2L2 learners.

## Narratives

The research methodology in this paper involves narrating a story. Here, we focused on narratives in this study to investigate how second language users (L2) use depicting signs. Research related to narrative tasks is well-established (see Robinson, 1995; Foster and Skehan, 1996; Skehan and Foster, 1997, 1999; Bygate, 1999). According to Albert and Kormos (2011), this research methodology usually involves creation of a story in response to a stimulus, such as a picture or a film. Methods of language teaching also often employ tasks that entail narrating or retelling a story, allowing students to use their imagination to generate new ideas (Swain, 1985). L2 spoken language instruction employs communicative and task-based language methods, including telling narratives (Albert and Kormos, 2011).

There are a number of studies related to oral narrative performance tasks in spoken language research. These tasks generally involve some storytelling and an opportunity to use one's imagination (Albert and Kormos, 2011). Narrating a story in a second language is an increasingly popular language elicitation tool; however, researchers affirm that it is one of the most difficult and challenging aspects of language production (Ellis, 1987; Robinson, 1995). Challenges include remembering the series of events in the story and establishing a variety of viewpoints, as well as mastering lexical, syntactic, and pragmatic linguistic features (Norbury et al., 2014). Constructing a narrative is challenging because both language and cognitive tasks occur at the same time. Producing cohesive, coherent, and structured narratives requires sophisticated language and cognitive skills (see Bamberg and Damrad-Frye, 1991). Gulamani et al. (2022) expressed that narrative is an interesting area of study in L2 acquisition since it can provide us with a rich source of data related to linguistic and cognitive tasks as well as data that compare language fluency among M2L2 late learners with those of early learners.

## Gestures

Though there has been a great deal of research on the topic of gesture in psychology and linguistics, researchers do not have an agreed-upon definition of *gesture*. Kendon (1986), who advocated for studying gesture in a second language context, recognized that gestures may be considered gradient or gestural and are integral to the very working of the system as a language (Kendon, 2008). McNeill described a gesture as "an unwitting, non-goal-directed action orchestrated by speaker-created significances, having features of manifest expressiveness" (2016, p. 28). Furthermore, McNeill (2016) emphasized that an expressive action is part of the process of speaking that enacts imagery. Silent gestures and co-speech gestures (those gestures that co-occur with speech) (McNeill, 1992; Kendon, 2004) are commonly used by individual naïve gesturers. Capirci et al. (2022) described how throughout most of the twentieth century, "different models proposed to describe signed languages were based on a hierarchy: only the lexical units (i.e., standardized in form and meaning signs) were considered at the core of the language, while the productive signs (i.e., iconic constructions) were pushed to the linguistic borderline, closer to the level of gesticulation and mime" (p. 6,365).

One can distinguish gestures used by sign naïve gesturers (1) to support or complement speech (co-speech) or (2) as silent gestures. This might be a conscious process, but may well be unconsciousness. Learners of M2L2 might recruit gestures as a way to express themselves when they do not master a language yet. So they might produce a gesture for an object in case they lack the lexeme. In this case, gestures serve another role as a deliberate strategy to get the information across. Some gestures resemble sign language lexemes. For example, Brentari et al. (2012) describes hand-as-object gestures and Ortega et al. (2020) describes some iconic transparent lexemes (e.g., drink, play-piano, etc).

Gullberg (2006) explained how gestures are relevant to the study of Second Language Acquisition (SLA): "Gestures can therefore be studied as a developing system in their own right both in L2 production and comprehension" (p. 103). Gestures are important in M2L2 studies, namely, since it is possible that beginning sign language learners resort to gestures in absence of any knowledge of sign language. It is possibility that beginning sign language learners also use transfer of gestures, just like learners of other language pairs might transfer a lexeme or grammatical signs of their L1 in their L2 (Chen Pichler and Koulidobrova, 2016). It is possible that some sign language learners might depend on their gestural repertoire in their learning process when they do not know how to produce the signs or remember how to sign them.

When acquiring a second language, learners draw from any available semiotic resources and not only from their linguistic experience (Ortega et al., 2020). Research in the field of sign language has shown that signed languages may share some properties with gesture especially the locative relationships between referents and participants involved in action (Casey S., 2003; Casey S. K., 2003; Liddell, 2003a,b; Kendon, 2004; Schembri et al., 2005). Schembri et al. (2005) tested deaf native signers of Australian Sign Language (Auslan), deaf signers of Taiwan Sign Language (TSL), and hearing non-signers using the Verbs of Motion Production task from the Test Battery for ASL Morphology and Syntax. They found that that the handshape units, movement and location units appear to be very similar between the responses of non-signers, Auslan signers and TSL signers. This confirm the other data that claim that depicting handshape constructions are blends of linguistic and gestural elements (Casey S., 2003; Casey S. K., 2003; Liddell, 2003a,b; Kendon, 2004; Schembri et al., 2005). M2L2 learners do have access to a repertoire of gestures (Boers-Visker, 2021a,b).

There is a body of literature that shows that there are some similarities between some gestures and signs. Ortega et al. (2019) suggested that gestures that overlap in form with signs are called "manual cognates." Ortega and Özyürek (2020) found that the gesturers used similar systematic signs and that many signs involving acting, representing, drawing and molding were considered cognates.

## Depiction

Depicting is a common part of everyday communication. Clark's (2016) explained that people use a basic method of communication through describing, pointing at things, and "depicting things with their hands, arms, head, face, eyes, voice, and body, with and without props" (p. 324). Some examples Clark's (2016) described include iconic gestures, facial gestures, quotations of many kinds, full-scale demonstrations, and make-believe play. Depiction is used by all (spoken and signed) language users, and that for sign languages, this is accomplished by using depicting handshapes and signs. Depiction can also include behaviors that are not actually happening but are a representation of behaviors or events (Goffman, 1974). Gesturers have been shown to deploy depiction in such signs as "like this," where "like this" functions to introduce the depiction, which can simply be a gesture (Fillmore, 1997; Streeck, 2008). Cuxac (1999, 2000) proposed that, with depiction, a signer can "tell by showing," Cuxac driven by an illustrative goal.

Ferrara and Halvorsen (2017) and Ferrara and Hodge (2018) applied Clark's theory on spoken communication to signed languages. Clark's (2016) theory was based on Peirce's (1994) work which identified the foundational principles of categorization of semiotic signs into symbols, indices, and icons. Ferrara and Halvorsen (2017) and Ferrara and Hodge (2018) proposed that there are different ways to display signs based on the signer's intentions.

The main function of verbs is "to encode meaning related to action and states" (Valli et al., 2011, p. 133). In sign language literature, Liddell (2003a) first coined the term "depicting verbs." Thumann (2013) identifies depiction as "the representation of aspects of an entity, event, or abstract concept by signers' use of their articulators, their body, and the signing space around them" (p. 318). Valli et al. (2011) explained, "like other verbs [depicting verbs] contain information related to action or state of being" (p. 138). An example of depiction in ASL is BIKE-GO-UP-THE-HILL (translation: "The bike is being ridden up a hill"). For this paper, we will use "depictive signs" as an umbrella term for the categories we are analyzing.

Conceptual blending is the combination of words and ideas to create meaning in various ways. Liddell (2003a) extended Fauconnier's (2001) conceptual blending theory to ASL to explain the structure of depicting signs. Valli et al. (2011) offered an example of blending: two people are sitting in an office having a conversation. One of the interlocutors wants to describe the street where she lives. She could set up objects on the table as a visual representation of her street; she might use a book to represent her house, a folder to represent her neighbor's house, and a pen to represent the railroad tracks at the end of the street. Liddell (2003a) describes how these real items on the table represent part of the imagined "scene" of the street where she lives. Because ASL is a visual language, ASL users can present conceptual blending by using their fingers, hands, arms, body, and face as the "objects" that represent the scene in signing space. Dudis (2004) offered another example: to describe a rocket flying in space, a non-signing college professor might use a pen to represent a rocket flying in space. Similarly, in ASL, signers could represent the rocket by using the handshapes of either a "1" or "R" instead of a pen. When signers represent an entity or event that is not actually present, they may choose to use depicting handshapes, signs and space to make unseen entities visible (Thumann, 2013).

In a study that examined an ASL educational video series, Thumann (2013) found that native ASL users produced depiction an average of 20.44 times per minute. In another study, ASL-English interpreters were asked to interpret two texts twice, 12 years apart (Rudser, 1986). Their interpretations 12 years later included a greater number of depicting handshapes, suggesting that an increased usage of depicting handshapes aligns with a higher level of ASL fluency. In a similar study, deaf children whose mothers who were native signers displayed a greater usage of depicting handshapes compared to deaf children whose mothers who were non-native signers (Lindert, 2001). Halley (2020) suggested that non-native signers may struggle with comprehending and producing depiction, especially the depicting handshapes and signs. Thumann (2010) agreed that second language learners of ASL find depiction challenging to comprehend and produce. Wilcox and Wilcox (1997) and Quinto-Pozos (2005) likewise found that second language learners of ASL have difficulty producing depicting handshapes. These studies support the evidence in this study—that not all depicting signs are easy for M2L2 learners to acquire. However, in another study, Boers-Visker (2021a,b) conducted a study with 14 novel learners of Sign Language of the Netherlands (NGT) over a period of 2 years. The NGT learners were asked to produce sign language descriptions of prompts containing various objects that could be depicted using a depicting handshape. They found that the practice of denoting an object with a meaningful handshape was not difficult to learn.

## Depicting signs

Frishberg (1975) conducted one of the earliest studies related to depicting handshapes in sign language; she described depicting handshapes as "hand-shapes in particular orientations [used] to stand for certain semantic features of noun arguments"

(p. 710). A subsequent body of work has contributed to the description and analysis of depicting handshapes in almost all known sign languages (Schembri, 2001; Zwitserlood, 2012). Referents in handshapes signals that it has certain salient characteristics, such as size and shape, or that the referents represent a class of semantically related items (Cormier et al., 2012).

Depicting signs entail information related to the location, movement, path, and/or manner of movement of an argument of the verb, as well as the two locations of both referents in relation to each other (Schembri, 2001). Whole entity depicting handshapes entail handshapes that represent an item from a semantic group. For example, the Depicting Handshape (DH)-3 handshape represents a car, motorcycle, or a bike; the DH-1 handshape represents upright beings (people and animals); and the bent DH-V handshape represents people sitting or small animals such as cats and birds. Handling depicting handshapes represent a hand holding an item. For example, the flat-DH-C handshape represents holding flat items with some thickness, such as a book, piles of papers, or a cereal box. The DH-S handshape represents holding cylindrical items. When a signer uses a handling depicting handshape, it denotes that an agent is manipulating an object in a particular way (e.g., holding a paint roller; hands on steering wheel). As the name implies, body part depicting handshapes represent a part of the body of a human or animal. The body part depicting handshape DH-V (downward) represents the legs of a human or upright animal, and the DH-C (spread) represents the claws of an animal. Likewise, size-and-shape specifiers describe the size or shape of an object. For example, the DH-F handshape using one hand could represent a circular object such as a coin or using both hands to represent a cylindrical object by moving apart from each other (e.g., a stick, pipe, or small pole). Depicting signs also include locations that are encoded in the signing space.

Depicting signs may include one or two hands. For example, a signer might use one hand to represent a person standing up and another hand to represent a small animal. Schembri (2003) described how it is possible simultaneously for one hand to depict a whole entity depicting handshape while the other hand employs a handling depicting handshape. Schembri (2003) also explained that one of the depicting handshape types could represent part of a static or moving referent and could be combined with verb stems that represent the motion or location of a referent.

Some studies of non-signers have shown that non-signers use depicting handshape-like gestures to express motion events (Singleton et al., 1993; Schembri et al., 2005). However, in a study of Dutch signers, depicting handshapes used were found to be highly conventionalized compared to non-signers' gestures (Boers-Visker and Van Den Bogaerde, 2019). Boers-Visker and Van Den Bogaerde (2019) compared how two L2 subjects and three L1 subjects used depicting handshapes and found that both L2 subjects used depicting handshapes less frequently than the L1 subjects. The visual representation of depicting handshapes and depicting signs is new for many M2L2 students (Boers-Visker, 2021a,b). There are a few recent studies that describe how M2L2 learners acquire depicting handshapes and signs. Marshall and Morgan (2015) studied British Sign Language (BSL) M2L2 learners who had been learning BSL for 1–3 years. The researchers found that the learners were aware of the need to use depicting handshapes to represent objects but had difficulties in choosing the correct depicting handshapes although the location did not lead to much difficulty. In another study, Ferrara and Nilsson (2017) looked at how Norwegian Sign Language (NSL) learners used depicting handshapes and signs to describe an environment. They found that the learners often resorted to lexical signs instead of depicting handshapes and signs and used lexical signs marked for location. In summary, these studies showed that M2L2 students found it difficult to acquire depicting handshapes and that it is a complex system to learn.

## Four types of depicting signs

Depicting signs— (Frishberg, 1975; Supalla, 1986)—"are a productive semiotic resource for ironically representing entities, spatial relationships, handling actions and motion events in signed languages" (for overviews of their properties see Emmorey, 2003; Zwitserlood, 2012) (McKee's et al., 2021, p. 95). Using a cognitive linguistics framework, depicting signs entail their analog character and function in discourse (Liddell, 2003a; Dudis, 2008; Ferrara, 2012). The the depicting signs identified in this study included the four main types of depicting signs in the in McKee's et al. (2021) study. We coded the four types of depicting signs in our data: (1) Entity depicting signs; (2) Body part depicting signs; (3) Handling depicting signs; and (4) Size-and-shape specifiers (SASS), as follows (the information/codes below were adapted from McKee's et al., 2021, p. 100–101).

### Entity depicting signs

The handshape represents a whole or part of an entity that belongs to a closed semantic category, for instance human beings or vehicles. Whole Entity (Engberg-Pedersen, 1993) or semantic depicting handshapes (Supalla, 1986) have also been used as alternative names in the literature. The handshape can combine with a movement that indicates motion path and/or manner of the entity in space (unlike size-and-shape specifiers).

### Body part depicting signs

Body parts of an animate referent, e.g., legs, eyes, feet, head, are mapped onto the signer's fingers or hands.

## Handling depicting signs

In handling depicting signs, the movement that combines with a depicting handshape imitates how an object is touched or handled. Padden et al. (2013) explained two strategies within this category depending on which iconic feature is depicted by the selected handshape: the action of the hands or the shape properties of the object being handled.

a. *Handling (HDS-h)*: the handshape depicts a hand manipulating an object, e.g., grasping the handle of a toothbrush and moving the handshape at the mouth as if brushing.
b. *Instrument (HDS-i)*: the handshape depicts a salient feature of the object itself, e.g., the extended index finger represents a whole toothbrush, with lateral movement across the mouth that imitates the orientation of a toothbrush in use.

## Size-and-shape specifiers

These describe the visual-geometric structure of a referent (see Supalla, 1986) and this study we distinguish three sub-categories:

a. *Static SASS (SASS-st)*: The size and/or shape of an object or part of an object is either directly mapped onto the signer's hand (e.g., a flat B-handshape representing a sheet of paper), or the distance between the signer's hands or fingers shows the size of the referent, (e.g., two flat handshapes, palms facing, to show the width of a box). Unlike entity depicting signs, handshapes do not specify a particular semantic class of referents but categorize them in a broader sense into flat objects, round objects, thin objects, etc. Another difference from entity depicting signs is that no path movement is involved in static SASS. The repeated articulation of a static SASS can depict a quantity of objects (e.g., a stack of books).
b. *Tracing SASS (SASS-tr)*: The signer uses the index fingers or whole hands to trace the outline of an object in the air, e.g., the triangular shape of a traffic sign. The hand movement involved in this category of depicting signs specifies the shape or extent of a referent, unlike in entity depicting signs where path movement describes the motion of a whole entity.
c. *Element SASS (SASS-el)*: These are descriptions of non-solid element such as water, light or vapor. Although such elements do not have a clearly delineated size or shape their depiction shares properties with SASS (see also Supalla, 1986 "texture and consistency morphemes"). Element depictions are rarely represented in experimental studies but need to be accounted for in a M2L2 acquisition study.

FIGURE 1
First depicting sign of a native signer: Example of EDS: Sylvester the cat walking upright similar to a human being from point A to point B.

The first main type of depicting signs are called entity depicting signs (EDS), which represents a whole or part of an entity such as a human being or vehicle. The signer retelling the *Canary Row* story could use EDS to show Sylvester the cat walking upright, like a human being. The handshape consists of an index finger that shows an upright person in a path of motion. The signer could use a "1" handshape to depict a cat walking from point A to point B (see Figure 1).

The second main type of depicting signs is called body part depicting signs (BPDS), where animate parts of a body (legs, eyes, feet, head, etc.) are mapped onto the signer's hands or fingers. In the *Canary Row* example, when Sylvester the cat is kicked out of a building and lands in the garbage, the signer could use a "S" handshape to depict a cat's head hitting the garbage (see Figure 2).

The third main type of depicting signs is called handling depicting signs (HDS), which combines movement with depicting handshapes to imitate how an object is touched or handled. Here, we distinguish two sub-categories based on Padden et al. (2013)'s work in this area: Handling (HDS-h) and Instrument (HDS-i). HDS-h is when the handshape depicts a hand manipulating an object, e.g., grasping the handle of a toothbrush and moving the handshape at the mouth as if brushing. In the *Canary Row* example, the grandmother is seen holding the closed umbrella while hitting the cat, this could be depicted through an HDS-h as shown in Figure 3. HDS-I is related to the handshape that depicts a salient feature of the object itself, e.g., the extended index finger represents a whole toothbrush, with lateral movement across the mouth that

FIGURE 2
Second depicting sign related to BPDS used to describe the head "S" of the Sylvester the cat when he is kicked out of a building and hits his head in the garbage area.

FIGURE 3
Third depicting sign that shows HDS-h which the Grandmother is seen holding the closed umbrella when hitting the cat.

FIGURE 4
Fourth depicting sign entails an HDS-i where the hotel clerk is talking on a telephone.

imitates the orientation of a toothbrush in use. In the *Canary Row* example, the hotel concierge is talking on the phone. The signer could use the sign for "telephone" as part of HDS-i (see Figure 4). In another study, Padden et al. (2010) found a generational difference related to handling and instrument and SASS in two different sign languages, Al-Sayyid Bedouin Sign Language (ABSL) and Israeli Sign Language (ISL). They also found that while both ASL and ISL make full use of the size-and-shape specifiers and handling depicting handshapes, the depicting handshapes system of ASL includes more abstract entity depicting handshape, such as UPRIGHT-OBJECT and VEHICLE than ISL, which relies more on size-and-shape specifiers and handling depicting handshape.

The fourth main type of depicting signs shows the size-and-shape specifier (SASS) of an object. SASS describe the visual-geometric structure of a referent (Supalla, 1986). Under this SASS, there are three sub-categories: Static SASS, Tracing SASS and Element SASS. With Static SASS (SASS-st) the size and/or shape of an object or part of an object is either directly mapped onto the signer's hand (e.g., a flat B-handshape representing a sheet of paper), or is represented by the distance between the signer's hands or fingers to show the size of the referents. For example, in the *Canary Row* story, the signer might depict the size of the downspout that is attached to the building (see Figure 5). The Tracing SASS (SASS-tr) is when the signer uses the index finger or whole hands to trace the outline of an object in the air, e.g., the triangular shape of a traffic sign. For example, in the *Canary Row* story, the signer makes an outline with his/her index finger outlining a poster/sign on the wall (see Figure 6). The Element SASS (SASS-el) entails non-solid elements such as water, light or vapor. Not all SASS-el have a clearly delineated size or shape, but their depiction shares properties with SASS. For example, in the *Canary Row* story, the signer could depict the water trickling down the downspout pipes (see Figure 7).

## Research questions

Given the paucity of research on second language acquisition specifically in sign languages students, this study looks at these four main types of depicting signs. Students who were learning

FIGURE 5
Fifth depicting sign entails a static SASS where the signer depicts the size of the downspout that is attached to the building.

FIGURE 7
Depicting sign–element of water trickling down the downspout.

FIGURE 6
Sixth depicting sign entails a tracing SASS where the signer traces the poster on a building wall.

ASL as a second language and second modality were the focus of this research. The research hypotheses are that:

a. In a cross-section sample of M2L2 ASL students, students exhibit a common acquisition trajectory for the use of all types of depicting signs over time.
b. The advanced ASL groups would exhibit greater use of depiction signs compared to the beginning ASL groups.

The null hypotheses are that the students would not exhibit a common acquisition trajectory in the use of all types of depicting signs over time, and that there are no differences between the beginning and advanced ASL groups.

# Methods

The study reported in this article is part of a larger cross-sectional research project to investigate cognitive and task-based learning in M2L2 hearing students. Some other tests that were part of the larger research project include the Kaufman Brief Intelligence Test; ASL-Comprehension Test; Image Generator; Spatial Stroop; ASL Spatial Perspective; and ASL Vocabulary. All tests were counterbalanced. Analyses related to these other cognitive tasks are ongoing and will be disseminated in separate papers. This research project was approved by the Institutional Review Board and was conducted in accordance with the ethical guidelines laid out by the university.

## Participants

The sample included 75 hearing undergraduate students ($M_{age}$ = 21.2 years, $SD_{age}$ = 1.7 years) who were taking 3-credit college ASL courses of different levels. Of 59 participants who reported their gender identity, 61% identified as female, 37.3% identified as male, and 1.7% identified as non-binary. The participants were divided into three subgroups based on their coursework. The ASL 1 Group represents those who were enrolled in a 3-credit ASL 1 course for one semester (15 weeks); the ASL 2 Group were enrolled in the second level ASL course (either because they took ASL 1 already or already had some ASL skills), and the ASL 3+ Group were in the third level ASL course or higher. There were no significant differences between the three ASL groups based on their age, $F(2, 56) = 0.903$, $p = 0.411$, or gender identity, $F(2, 56) = 1.645$, $p = 0.202$.

## Materials

The material consisted of short stimulus clips from *Canary Row*, a series of Sylvester and Tweety cartoons (Freleng, 2004). These clips were used as an effective elicitation tool for narrative retellings (McNeill, 1992). Each of the clips is a few minutes long. All three clips were selected to elicit signed stories from M2L2 students.

The first clip shows Sylvester and Tweety across from each other in different buildings. Sylvester is on a lower level of a building and Tweety is on an upper level of a building across the street. Tweety is in his bird cage. Sylvester uses binoculars to look for Tweety. Tweety also has a set of binoculars. Tweety chirps and makes some noises. Sylvester becomes excited and runs across the street to enter the building Tweety is in. There is a sign on the building that says, "No dogs or cats allowed." As soon as Sylvester enters the building, he gets kicked out and lands in the garbage with trash on his head.

In the second clip, Sylvester walks back and forth in an alley. Across the street, Sylvester sees a dancing monkey wearing a shirt and cap next to a man with a mustache who is playing a musical box. Sylvester calls to the monkey and entices it with a banana. The monkey follows Sylvester behind the bush/wall. Sylvester changes into the monkey's clothes and acts as the monkey, carrying a cup to collect coins. Tweety sees Sylvester and tweets. Next, Sylvester climbs up the drain pipe toward Tweety. As soon Tweety sees Sylvester at the window, he escapes his cage and flies into the Grandmother's apartment. Sylvester begins to chase Tweety in the apartment. When Sylvester runs into the Grandmother, he stops and acts like a monkey in front of her. While the Grandmother is talking to Sylvester, he continues to look around for Tweety under the table cloth, chair, Grandmother's long dress, and the rug. The grandmother takes out a coin from her wallet and drops it in a cup that Sylvester is holding. Next, Sylvester grabs his hat and pulls it then suddenly, he gets hit by the Grandmother with an umbrella. Eventually Sylvester becomes dizzy and leaves the room.

In the final clip, the desk clerk answers an old-fashioned telephone and can be seen talking affably on the phone. Next, Sylvester is shown sitting in a mailbox and eavesdropping on the clerk's phone conversation. Sylvester becomes sneaky and appears at the Grandmother's apartment door disguised as a porter and knocks at her door. There is a small rectangular window above the door; the Grandmother can be seen talking to Sylvester through the transom window at the top of the door. Sylvester asks the Grandmother to open the door and she says OK. Next, Sylvester enters the apartment, looks around the room; he picks up the bird cage that is covered in a cloth and a small suitcase. He leaves the apartment with the bird cage and suitcase and throws out the suitcase. He picks up the bird cage and walks down the stairs. Sylvester carries the covered bird cage into the alley and puts it on top of a box. Sylvester removes the cover and, to his surprise, the Grandmother is in the bird cage instead of Tweety. The Grandmother hits Sylvester with an umbrella and chases him down the street.

## Procedures

An informed consent form and a video-release form were shared with the participants prior to the testing. By signing these forms, participants allowed researchers to record their signing, and share their video data for the purposes of presentation, publication, and teaching. Participants were allowed to continue with the study even if they did not wish to have their video data released but gave their informed consent. Participants who did not wish to have their videos shared gave us permission to collect their data and use it for analysis, but their videos were not used for the creation of still images, videos, or presentation of data in public. All participants were given language background questionnaires and asked to rate their ASL skills proficiency.

The ASL students watched the cartoon *Canary Row* video clips and were asked to "retell the story as if you were telling it to a deaf friend" using gestures or sign language. Participants were tested individually and compensated $20 for their time. Two research assistants, who were hearing English-ASL interpretation majors, provided an informed consent form and explained the benefits and risks of the study in spoken English. These instructions were read to the participants: "For this part of the study, you will watch a short clip from a Sylvester and Tweety cartoon. You will sign in ASL what you saw in the cartoon clip. I will show you the clip two times before I ask you to sign the story." Participants were also told that they could use gesture, mime, sign, or a combination. The intent of these instructions was to avoid causing participants to feel uncomfortable or limited regarding their expressive sign language skills. They were encouraged to use any semiotic device they deemed appropriate, especially if they were not feeling confident in their ASL skills. In a private testing room where there were no other distractions, participants sat in front of a desktop computer to watch the cartoon clips. On top of the computer was a built-in webcam running in the background during testing to capture the student's signing. Participants were allowed to watch the video up to two times before retelling the cartoon stories using whichever semiotic devices needed to complete the retelling task. Participants were encouraged not to share the content of the test with other potential subjects outside of the testing sites. Participants were tested three times; each time they watched a different clip from Canary Row.

# Depicting signs analysis

Videos of participants' retelling the cartoon clips were coded and analyzed using ELAN, a video annotation software program developed by researchers at the Max Planck Institute of Psycholinguistics in Nijmegen, Netherlands (Crasborn and Sloetjes, 2008; ELAN, 2021). In ELAN, tiers for coding purposes were developed to capture each of the depicting signs. ELAN was used to track how many times (tokens) each tier was marked. Researchers marked the tokens to indicate whether the discourse stretch presented instances of the four main types of depicting signs: (1) Entity depicting signs; (2) Body part depicting signs; (3) Handling depicting signs; and (4) Size-and-shape specifiers (SASS). Annotations in ELAN were made on five tiers for the verbs and the four different depicting signs. The figures below provide examples of what the annotations look like for a fragment where the signers in the video (not shown) are producing depicting signs. Figure 8 comprise an annotation that show tiers that were created; tokens were marked "correct" if the signer produced these depicting signs correctly. If they were not produced at all or produced incorrectly, they were left blank. The annotations show and "Depicting−1," indicating the stationary sign or depicting handshape that was produced. For example, cars parked in the driveway.

A total of four student research assistants—two hearing students who are children of deaf adults and native-like signers, one deaf and native signer, and one hearing near-native signer—collaborated to perform analyses and complete the coding for each tier. The codings were spilt into three different ratings: 1. Correct sign production; 2. A mix of correct and incorrect sign production; and 3. Incorrect sign production. For instance, in the mix of both correct and incorrect signs, some M2L2 signers would produce the correct form (handshape) but the movement or location in the signing space is incorrect. Research shows that sometimes these gestures have the same form as signs (Ortega et al., 2019). For example, the "incorrect" handshapes might not be incorrect in this respect. However, these errors are part of the learning process and could be seen as an interlanguage phenomenon. Boers-Visker and Van Den Bogaerde (2019) showed that sign-naïve gesturers use handshapes in their features that deviate from the lexeme. Learners might produce these incorrect handshapes during the first stages of their learning process (Janke and Marshall, 2017).

The total number of depicting signs in each of the three retelling was divided by three to give the average number of depiction sign tokens per video. However, one limitation of the method was that not all participants had three clear videos of them retelling each of the three clips. Approximately 30% of the videos (68 videos of 225 possible retellings) were unscoreable because they were either choppy, frozen, or the participant was partially outside of the video frame. For those who had some unscoreable videos, the total tokens per video was divided by the number of scoreable videos. This ensured we could compare students across different ASL levels.

## Results

A one-way analysis of variance (ANOVA) was performed to determine if the ASL groups differed in their ASL Comprehension Test (ASL-CT) performance. All three ASL groups performed significantly different from each other, $F(2, 72) = 19.088$, $p < 0.001$, PES = 347, 95% CI = 0.165, 0.479. *Post-hoc* analyses with Bonferonni corrections to the alpha revealed that the ASL 1 Group ($M$ = 51% correct; $SD$ = 10%) performed worse ($p = 0.031$) than the ASL 2 Group ($M$ = 59% correct: $SD$ = 10%) and the ASL 3+ Group ($p < 0.001$; $M$ = 69% correct; $SD$ = 10%), the ASL 2 Group performed worse than the ASL 3+ Group ($p = 0.026$), and the ASL 3+ Group performed better than the ASL 1 ($p < 0.001$) and ASL 2 Group ($p = 0.026$).

Two raters who are non-deaf native ASL signers born to deaf, signing parents coded the Entity-Static and Entity-Movement tokens. Their inter-rater reliability was $r$ (67) = 0.811, $p < 0.001$. One deaf native signer and one non-deaf and non-native ASL signer coded the remaining DV variables. Their inter-rater reliability was $r$ (42) = 0.918, $p < 0.001$. To determine if there was a relationship between ASL-CT performance and the total number of depicting sign tokens identified, a significant positive correlation was found, $r$ (69) = 0.387, $p < 0.001$, suggesting that the more ASL comprehension a student has, the more ASL production with DV was observed. A multivariate ANOVA was computed with number of depicting sign tokens as the

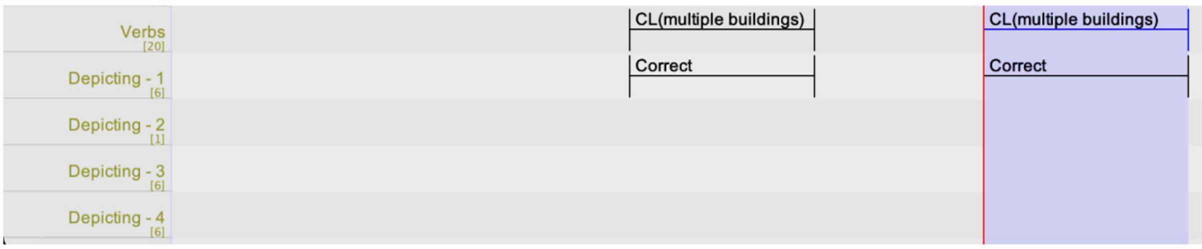


FIGURE 8
Annotations in the data on a selection of tiers. The affixes verbs in their tier titles (first column) denote the sign(s) or verbs that were made.

TABLE 1 Three ASL groups' performance on producing the four types of depicting signs.

| Dependent variable | ASL 1 tokens mean (SD) | ASL 2 tokens mean (SD) | ASL 3+ tokens mean (SD) | MANOVA ASL group Main effects | Pairwise comparisons 95% CI (lower, upper) | Correlation with ASL-CT |
|---|---|---|---|---|---|---|
| EDS | 2.7 (2.3) | 1.1 (0.9) | 2.2 (1.8) | $F$ (2, 69) = 3.257 $p$ = 0.045 PES = 0.086 | ASL 1 > ASL 2 $p$ = 0.029 (0.061, 3.151) ASL 1 = ASL 3+ ASL 2 = ASL 3+ | 0.11 $p$ = 0.338 |
| SASS | 1.6 (2.0) | 2.9 (3.5) | 3.5 (3.0) | $F$ (2, 69) = 3.666 $p$ = 0.058 PES = 0.079 | ASL 1 < ASL 3+ $p$ = 0.046 (0.023, 3.870) ASL 1 = ASL 2 ASL 2 = ASL 3+ | 0.380 $p$ = <0.001 |
| BPDS | 3.0 (2.4) | 1.8 (2.0) | 3.8 (3.2) | $F$ (2, 69) = 2.111 $p$ = 0.129 PES = 0.058 | N/A | 0.305 $p$ = 0.009 |
| HDS | 1.6 (1.0) | 2.4 (1.9) | 3.5 (2.6) | $F$ (2, 69) = 7.203 $p$ = 0.001, PES = 0.186 | ASL 1 = ASL 2 ASL 2 < ASL 3+, $p$ = 0.026 (-2.677, 0.401) ASL 1 < ASL 3+, $p$ = <0.001 (0.660, 3.144) | 0.428 $p$ = <0.001 |

CI, confidence interval; EDS, entity depicting signs; SASS, Size-and-Shape Specifiers; BPDS, body part depicting signs; HDS, handling depicting signs; PES, partial eta square.

dependent variable, depicting sign type (EDS, SASS, BPDS, HDS) as the within subject variable and ASL class level (ASL 1, ASL 2, ASL 3+) as the between subject variable. The analysis revealed significant group main effects for EDS, SASS, and HDS ($p$ < 0.05) but not BPDS (see Table 1 and Figure 9).

The following figures provide descriptive examples of the students producing different types of depicting signs. Figure 10 shows an ASL student using depicting sign, the stationary depicting handshape, to show where the entity is established in the signing space (e.g., CL-planes on a runaway). In the last example, Figure 11 shows an ASL student using depicting signs that show the action and motion of an entity (e.g., CL- a car going uphill).

## Discussion

The three groups of ASL undergraduate college students were more heterogenous than homogenous in their ASL expressive skills as evident in the groups' standard deviations. Regardless, the results revealed that producing SASS and HDS are skills that improve as students advance in their L2 training and both have a positive relationship with an independent measure of ASL comprehension. While EDS did not correlate with ASL comprehension and the ASL 2 students produced less of this depicting sign than the ASL 1 students but did not differ from the ASL 3+ students. The frequency of BPDS among the three groups of L2 learners was not different although their ability to produce BPDS was correlated with their ASL comprehension.

The authors postulate that it is possible the ASL 1 signers gesture concepts in a way that it produced a depicting sign before they know the actual sign for the concept, hence the less EDS tokens among those in ASL 2. It is possible that some gesturing skills students bring to ASL 1 might be helping them produce descriptions that are pidgin-like signs mixed with gestures they spontaneously produce. Occhino and Wilcox (2017) discussed how the interlocutor may categorize an articulation as a sign or gesture differently based on their linguistic experience. A possible limitation is that those students who learned ASL in their ASL classes became comfortable with using gestures and acting as opposed to telling the story using the depicting handshapes or tracing depicting handshapes to describe the size or shape of an object. As students' progress through their ASL education, they are exposed to new vocabulary and learn more prescriptive rules of ASL. Over time, the ASL students may have learned more of the formal rules related to use of depicting handshapes and describing objects or people. As discussed earlier in this article, the "hand-as-object" gestures and entity depicting handshape produced by non-native signers could be similar to each other. Previous research suggests that M2L2 learners could access their repertoire of gestures as substrate upon which they could build their knowledge (Marshall and Morgan, 2015; Janke and Marshall, 2017). It is very possible that learners used more gestures in ASL 1 and in the more advanced ASL classes, learners used more depicting signs including depicting handshapes. Boers-Visker (2021a,b) suggested "that the commonalities between gestures and signs facilitate the learning process, that is, we are dealing with an instance of positive transfer" (p. 23).

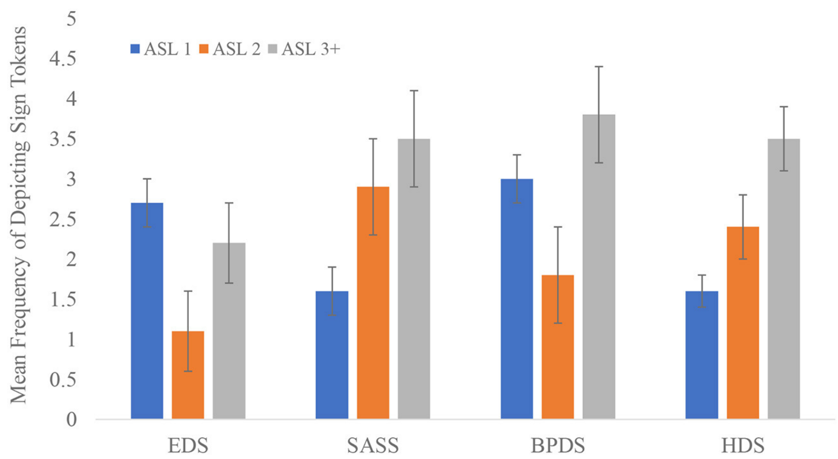


FIGURE 9
Average frequency of depicting signs per each four depiction types and each ASL group. Error bars represent the standard error. EDS, entity depicting signs; SASS, size-and-shape specifier; BPDS, body part depicting sign; and HDS, handling depicting sign.

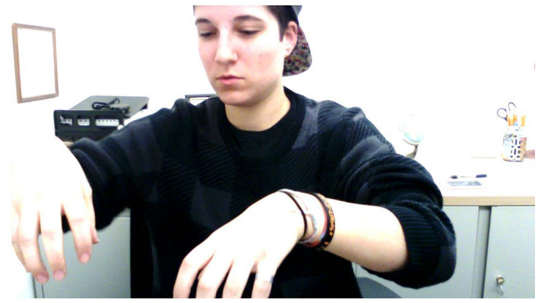

FIGURE 10
ASL student using depicting signs to show multiple buildings in signing space.

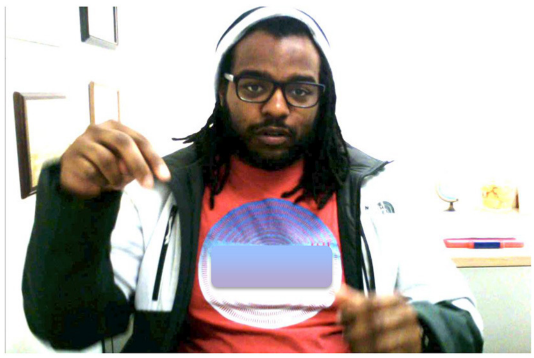

FIGURE 11
ASL student using type 3 depicting signs: a depicting handshape showing a cat walking down the stairs.

Future analyses should include more specific linguistic features—eye gaze, mouth movement, depicting handshapes (including depicting handshape entity), phonological features, manual and non-manual articulators, location, and use of space—and compare them between groups. The three groups with increasing levels of proficiency makes this a cross-sectional study. Future studies could follow all the same participants for a longer time, filming them at ASL 1, ASL 2 and 3+.

## Limitations of study

A potential limitation of this study is the utilization of videos that captured a two-dimensional model of language, instead of a three-dimensional model that would be found within a naturalistic setting. This may have impacted the raters' ability to see and read the gestures and signs in the videos. Another possible limitation is that it was difficult to disentangle signs from gestures. In several instances, it was a challenge to judge whether the signs were actually signs, and not gestures that resemble depicting signs.

Another possible limitation is that the subjects in this study could have had more socio-cultural exposure to signers and Deaf culture on campus. Given the visible presence of a large staff of sign language interpreters and the large number of deaf and hard of hearing individuals on campus, hearing study participants may have become accustomed to using gestures and/or signs and viewing how others use gestures and/or signs to communicate. The students were asked to imagine they were communicating with a deaf friend. The university has approximately 22,000 hearing students and 1,000 deaf and hard of hearing students. Although the participants were screened to make sure they did not have prior training in ASL and were not enrolled in other language courses, it is likely that they have had casual exposure and interaction with deaf and hard of hearing individuals in shared spaces such as classrooms, dormitories, dining halls, or other common spaces. Studies at other universities should also be conducted to see whether there are effects related to presence or absence of deaf and signing populations. Another limitation was that we did not observe how sign language teachers taught their ASL classes. There were more than 10 sections of ASL classes each semester and it is possible that, although each instructor followed the department's ASL curriculum, each likely had different teaching styles. Despite these limitations, we believe that the study provides valuable data on the acquisition of depicting signs, and that the findings presented offer a good starting point for further research.

## Future research directions

Our study yielded some answers but stimulated more questions. Some future research directions might include whether new signers require explicit instruction on the use of each type of depicting signs. Further cross-sectional and/or longitudinal studies are needed to analyze the later stages of learning of all four depicting signs and to measure the amount of improvement at each level of sign languages. Furthermore, research is needed to compare the learning trajectories for all four types of depicting signs in M2L2 ASL users with the trajectories of learners of signed languages of other countries. The large sample size in this study is a strength of our study which could lead to possible future research directions.

One suggestion for the future is to investigate how deaf ASL signers produce these depicting signs based on their frequency and the duration of each depicting signs, then compare those data with M2L2 hearing ASL students at other universities.

We did not ask our subjects whether they took any acting classes, as that might influence their ability to produce more depicting handshapes and signs. This would be another interesting study to compare subjects who took acting classes with subjects who never took acting classes and to test whether their depicting signs change over time. Ortega et al. (2020) found that hearing signers create expectations related to the form of iconic signs that they have never seen before based on their implicit knowledge of gestures. More studies are needed to better understand the role of what is traditionally considered "transfer" from L1 to L2; i.e., the extension of articulatory gestures from multimodal use of spoken languages to sign languages. Another area for study would be to investigate whether and how ASL teachers rely on hearing students' knowledge of a gestural repertoire to teach them depicting signs. Future research could also ascertain best practices in teaching depicting signs to maximize ASL learners' skill development. These lines of inquiry may serve as a guide for future evaluations of ASL pedagogies.

Future research also should include other variables and their effects on M2L2 learners who learn sign language. For example, Albert and Kormos (2011) wanted to see if creativity had a role in second-language oral task performance. They tested the creativity of Hungarian secondary school English learners using a standardized creativity test. Participants also performed two versions of a narrative task which included the numbers of words and narrative clauses, subordination ratio, lexical variety, and accuracy. They found that students who invented a high number of solutions on a creativity test did more talking. It is very possible that in a foreign language setting, students who talk more might create more opportunities for themselves to use the language in narrative tasks and have the beneficial effects of offering more output compared to students who do not talk as much or who score much lower on a creativity test. They concluded that some aspects of creativity might have an effect on the amount of output students produce, but not on the quality of narrative performance. Future studies should look into whether there is a connection between personalities and talkativeness. Future studies also should investigate the possible effect of students' personalities and whether personality impacts their output.

# Conclusion

M2L2 research is still in its infancy; we are still learning what a typical learning trajectory looks like in this population. Learning how to produce depicting signs in the visual-gestural modality is a challenging task, but this study demonstrated that M2L2 students can develop these skills. The ASL 3+ group appears to be able to produce a higher number of instances of depiction. The fact that depicting signs were not readily observed until after two semesters of college-level ASL instruction suggests that these four types of depicting signs may take more time for signers to learn; this finding has implications for ASL education. The task type in this study might have influenced the production of depicting signs.

There are few studies that consider the learner's interlanguage during development. Likewise, few studies have addressed acquisition of a signed language within the theoretical frameworks of second language acquisition. Research related to M2L2 from a language development perspective is still sparse; more research is needed to better identify the gaps in second language acquisition research findings and ascertain best teaching practices. Investigating the challenges in M2L2 development could contribute to the overall body of second language acquisition research. Future research, particularly cross-sectional and/or longitudinal studies, is needed to explore the trajectory of the acquisition of depicting signs, and to establish evidence-based approaches to teaching them to M2L2 students.

## Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## Ethics statement

The studies involving human participants were reviewed and approved by Rochester Institute of Technology. The patients/participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

## Author contributions

KK and PH: conceptualization, methodology, and formal analysis. KK: investigation, writing–original draft preparation, supervision, project administration, and funding acquisition. KK, GK, and PH: resources, writing–review and editing, and visualization. All authors contributed to the article and approved the submitted version.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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## References

Albert, A., and Kormos, J. (2011). Creativity and narrative task performance: an exploratory study. *Lang. Learn.* 61, 73–99. doi: 10.1111/j.1467-9922.2011.00643.x

Ashton, G., Cagle, K., Kurz, K. B., Newell, W., Peterson, R., and Zinza, J. (2014). Standards for learning American sign language. *Am. Council Teach. Foreign Lang.* 1–64.

Bamberg, M., and Damrad-Frye, R. (1991). On the ability to provide evaluative comments: further explanations of children's narrative competencies. *J. Child Lang.* 18, 689–710. doi: 10.1017/S0305000900011314

Boers-Visker, E. (2021a). Learning to use space. A study into the SL2 acquisition process of adult learners of sign language of the Netherlands. *Sign Lang. Linguist.* 24, 285–294. doi: 10.1075/sll.00062.boe

Boers-Visker, E. (2021b). On the acquisition of complex classifier constructions by L2 learners of a sign language. *Lang. Teach. Res.* 24, 285–294. doi: 10.1177/1362168821990968

Boers-Visker, E., and Pfau, R. (2020). Space oddities: the acquisition of agreement verbs by L2 learners of sign language of the Netherlands. *Mod. Lang. J.* 104, 757–780. doi: 10.1111/modl.12676

Boers-Visker, E., and Van Den Bogaerde, B. (2019). Learning to use space in the L2 acquisition of a signed language. *Sign Lang. Stud.* 19, 410–452. doi: 10.1353/sls.2019.0003

Brentari, D., Coppola, M., Mazzoni, L., and Goldin-Meadow, S. (2012). When does a system become phonological? Handshape production in gesturers, signers, and homesigners. *Nat. Lang. Linguistic Theory* 30, 1–31. doi: 10.1007/s11049-011-9145-1

Bygate, M. (1999). Quality of language and purpose of task: patterns of learners' language on two oral communication tasks. *Lang. Teach. Res.* 3, 185–214. doi: 10.1177/136216889900300302

Capirci, O., Bonsignori, C., and Di Renzo, A. (2022). Signed languages: a triangula semiotic dimension. *Front. Psychol.* 12, 802911. doi: 10.3389/fpsyg.2021.802911

Casey, S. (2003). "Relationships between gestures and signed languages: indicating participants in actions," in *Cross-Linguistic Perspectives in Sign Language Research: Selected Papers from TISLR 2000*, eds. A. Baker, B. van den Bogaerde, and O. Crasborn (Florianopolis, Brazil: TISLR).

Casey, S. K. (2003). "Agreement," in *Gestures and Signed Languages: The Use of Directionality to Indicate Referents Involved in Actions*. San Diego: University of California.

Chen Pichler, D. (2009). Sign production by first-time hearing signers: a closer look at handshape accuracy. *Cadernos de Saude* 2, 37–50. doi: 10.34632/cadernosdesaude.2009.2975

Chen Pichler, D. (2011). "Sources of handshape error in first-time of signers of ASL," in *Deaf Around the World: The Impact of Language*, eds. G. Mathur and D. Napoli (Oxford, UK: Oxford University Press), 96–121.

Chen Pichler, D., and Koulidobrova, H. (2016). "Acquisition of sign language as a second language," in *The Oxford Handbook of Deaf Studies in Language*, eds. M. Marschark and P. Spencer (Oxford, UK: Oxford University Press), 218–230.

Clark, H. (2016). Depicting as a method of communication. *Psychol. Rev.* 123, 324–347. doi: 10.1037/rev0000026

Cormier, K., Quinto-Pozos, D., Sevcikova, Z., and Schembri, A. (2012). Lexicalisation and de-lexicalisation processes in sign languages: comparing depicting constructions and viewpoint gestures. *Lang. Commun.* 32, 329–348. doi: 10.1016/j.langcom.2012.09.004

Crasborn, O., and Sloetjes, H. (2008). "Enhanced ELAN functionality for sign language corpora," in *3rd Workshop on the Representation and Processing of Sign Languages: Signs and Exploitation of Sign Language Corpora* (Marrakech, Morocco), 39–43.

Cuxac, C. (1999). "French sign language: proposition of a structural explanation by iconicity," in *International Gesture Workshop* (Springer: Heidelberg), 165–184.

Cuxac, C. (2000). *La Langue des Signes Française (LSF).* Les voies de l'iconicité. Faits de langues (Ophrys, Paris: Evry): 15–16.

Dudis, P. (2004). Body partitioning and real-space blends. *Cog. Ling.* 15, 223–238. doi: 10.1515/cogl.2004.009

Dudis, P. (2008). "Types of depiction in ASL," in *Sign Languages: Spinning and Unraveling the Past, Present and Future. Proceedings of the 9th Theoretical Issues in Sign Language Research Conference*, ed R. de Quadros (Florianopolis, Brazil: Editora Arara Azul, Petropolis), 159–190.

ELAN (2021). (*Version 6.2) [Computer software]. Nijmegen: Max Planck Institute for Psycholinguistics, The Language Archive*. Available online at: https://archive.mpi.nl/tla/elan (accessed December 16, 2022).

Ellis, R. (1987). Interlanguage variability in narrative discourse: style shifting and use of the past tense. *Stud. Second Lang. Acquis.* 9, 1–19. doi: 10.1017/S0272263100006483

Emmorey, K. (2003). *Perspectives on Classifier Constructions.* Mahwah, NJ: Lawrence Erlbaum Associates.

Engberg-Pedersen, E. (1993). *Space in Danish Sign Language: The Semantics and Morphosyntax of the Use of Space in a Visual Language*. Washington, DC: Gallaudet University Press.

Fauconnier, G. (2001). "Conceptual blending and analogy," in *The Analogic Mind: The Perspectives from Cognitive Science*, eds. D. Gentner, K. Holyoak, and B. Kokinov (Cambridge, MA: The MIT Press), 255–285.

Ferrara, L. (2012). *The Grammar of Depiction: Exploring Gesture and Language in Australian Sign Language (Auslan)* [dissertation] (Sydney: Macquaire University).

Ferrara, L., and Halvorsen, R. (2017). Depicting and describing meanings with iconic signs in norwegian sign language. *Gesture* 16, 371–395. doi: 10.1075/gest.00001.fer

Ferrara, L., and Hodge, G. (2018). Language as description, indication, and depiction. *Front. Psychol.* 9, 716. doi: 10.3389/fpsyg.2018.00716

Ferrara, L., and Nilsson, A.-L. (2017). Describing spatial layouts as an L2M2 signed language learner. *Sign Lang. Linguistic.* 20, 1–26. doi: 10.1075/sll.20.1.01fer

Fillmore, C. (1997). *Deixis Lectures on Deixis*. Stanford, California: Center for the Study of Language and Information.

Foster, P., and Skehan, P. (1996). The influence of planning and task type on second language performance. *Stud. Second Lang. Acquis.* 18, 299–323. doi: 10.1017/S0272263100015047

Freleng, F. (2004). *Looney Tunes: 28 Cartoon Classics [Cartoon; 2-disc premier edition, Canary Row is on disc 2).* Burbank, CA: Warner Bros. Entertainment Inc.

Frishberg, N. (1975). Arbitariness and iconicity: historical change in american sign language. *Language* 51, 676–710. doi: 10.2307/412894

Goffman, E. (1974). *Frame Analysis: An Essay on the Organization of Experience.* Cambridge, MA: Harvard University Press.

Gulamani, S., Marshall, C., and Morgan, G. (2022). The challenges of viewpoint-taking when learning a sign language: data from the "frog story" in british sign language. *Second Lang. Res.* 38, 55–87. doi: 10.1177/0267658320906855

Gullberg, M. (2006). Some reasons for studying gesture and second language acquisition (Hommage à Adam Kendon). *Int. Rev. Appl. Ling. Lang. Teach.* 44, 103–124. doi: 10.1515/IRAL.2006.004

Halley, M. (2020). Rendering depiction: a case study of an American sign language/english interpreter. *J. Interp.* 28, 3. Available online at: https://digitalcommons.unf.edu/joi/vol28/iss2/3

Hill, J., Lillo-Martin, D., and Wood, S. (2018). *Sign Languages: Structures and Contexts.* Oxfordshire, UK: Routledge.

Janke, V., and Marshall, C. (2017). Using the hands to represent objects in space: gesture as a substrate for signed language acquisition. *Front. Psychol.* 8, 2007. doi: 10.3389/fpsyg.2017.02007

Kendon, A. (1986). Some reasons for studying gesture. *Semiotica* 62, 3–28. doi: 10.1515/semi.1986.62.1-2.3

Kendon, A. (2004). *Gesture: Visible Action as Utterance*. Cambridge, UK: Cambridge University Press.

Kendon, A. (2008). Some reflections on the relationship between "gesture" and "sign." *Gesture* 8, 348–366. doi: 10.1075/gest.8.3.05ken

Liddell, S. (2003a). *Grammar, Gesture, and Meaning in American Sign Language.* Cambridge, UK: Cambridge University Press.

Liddell, S. (2003b). "Sources of meaning in ASL classifier predicates," in *Perspectives on Classifier Constructions in Sign Languages*, ed K. Emmorey (Mahwah, NJ: Erlbaum), 199–220.

Lindert, R. B. (2001). *Hearing Families with Deaf Children: Linguistic and Communicative Aspects of American Sign Language Development* [dissertation] (Berkeley, CA: University of California).

Marshall, C., and Morgan, G. (2015). From gesture to sign language: conventionalization of classifier constructions by adult hearing learners of British Sign Language. *Top. Cogn. Sci.* 7, 61–80. doi: 10.1111/tops.12118

McKee, R., Safar, J., and Pivac Alexander, S. (2021). Form, frequency and sociolinguistic variation in depicting signs in New Zealand Sign Language. *Lang. Commun.* 79, 95–117. doi: 10.1016/j.langcom.2021.04.003

McNeill, D. (1992). *Hand and Mind: What Gestures Reveal About Thought*. Chicago, IL: University of Chicago Press.

McNeill, D. (2016). "Gesture as a window onto mind and brain, and the relationship to linguistic relativity and ontogenesis," in *Handbook on Body, Language, and Communication*, eds. C Müller, A. Cienki, E. Fricke, S. Ladewig, D. McNeill, and S. TeBendorf (Berlin: Mouton de Gruyter), 28–54.

Norbury, C., Gemell, T., and Paul, R. (2014). Pragmatic abilities in narrative production: a cross-disorder comparison. *J. Child Lang.* 41, 485–510. doi: 10.1017/S030500091300007X

Occhino, C., and Wilcox, S. (2017). Gesture or sign? A categorization problem. *Behav. Brain Sci.* 40, 36–37. doi: 10.1017/S0140525X15003015

Ortega, G. (2013). *Acquisition of a Signed Phonological System by Hearing Adults: The Role of Sign Structure and Iconicity* (dissertation). London: University of College.

Ortega, G., and Morgan, G. (2015). Input processing at first exposure to a sign language. *Second Lang. Res.* 31, 443–463. doi: 10.1177/0267658315576822

Ortega, G., and Özyürek, A. (2020). Systematic mappings between semantic categories and types of iconic representations in the manual modality: a normed database of silent gesture. *Behav. Res. Methods* 52, 51–67. doi: 10.3758/s13428-019-01204-6

Ortega, G., Özyürek, A., and Peeters, D. (2020). Iconic gestures serve as manual cognates in hearing second language learners of a sign language: an ERP study. *J. Experiment. Psychol. Learn. Memory Cogn.* 46, 403–415. doi: 10.1037/xlm0000729

Ortega, G., Schiefner, A., and Özyürek, A. (2019). Hearing non-signers use their gestures to predict iconic form-meaning mappings at first exposure to signs. *Cognition* 191, 103996. doi: 10.1016/j.cognition.2019.06.008

Padden, C., Meir, I., Aronoff, M., and Sandler, W. (2010). "The grammar of space in two new sign languages," in *Sign Languages*, ed D. Brentari (Cambridge, UK: Cambridge University Press), 570–592.

Padden, C., Meir, I., Hwang, S.-O., Lepic, R., Deegers, S., and Sampson, T. (2013). Patterned iconicity in sign language lexicons. *Gesture* 13, 287–308. doi: 10.1075/gest.13.3.03pad

Peirce, C. (1994). *The Collected Papers of Charles Sanders Peirce I-VIII.* Cambridge, MA: Harvard University Press.

Quinto-Pozos, D. (2005). "Factors that influence the acquisition of ASL for interpreting students," in *Sign Language Interpreting and Interpreter Education: Directions for Research and Practice*, eds. M. Marschark, R. Peterson, E. Winston, P. Sapere, C. Convertino, R. Seewagen, and C. Monikowski (Oxford, UK: Oxford University Press), 159–187.

Robinson, P. (1995). Task complexity and second language narrative discourse. *Lang. Learn.* 45, 99–140. doi: 10.1111/j.1467-1770.1995.tb00964.x

Rosen, R. (2020). "Introduction - pedagogy in sign language as first, second, and additional language," in *The Routledge Handbook of Sign Language Pedagogy*, ed. R. Rosen (Oxfordshire, UK: Routledge), 1–14.

Rudser, S. (1986). Linguistic analysis of changes in interpreting: 1973-1985. *Sign Lang. Stud.* 53, 332–330. doi: 10.1353/sls.1986.0009

Schembri, A. (2001). *Issues in the Analysis of Polycomponential Verbs in Australian Sign Language (Auslan)* (dissertation). University of Sydney.

Schembri, A. (2003). "Rethinking classifiers in signed languages," in *Perspective on Classifier Signs in Sign Language*, ed. K. Emmorey (East Sussex, UK: Psychology Press), 3–34.

Schembri, A., Jones, C., and Burnham, D. (2005). Comparing action gestures and classifier verbs of motion: evidence from Australian sign language, taiwan sign language, and nonsigners' gestures without speech. *J. Deaf Stud. Deaf Educ.* 10, 272–290. doi: 10.1093/deafed/eni029

Schick, B. (1987). *The Acquisition of Classifier Predicates in American Sign Language* (dissertation). West Lafayette, IN: Purdue University.

Schönström, K. (2021). Sign languages and second language acquisition research: an introduction. *J. Eur. Second Lang. Assoc.* 5, 30–43. doi: 10.22599/jesla.73

Singleton, J., Morford, J., and Goldin-Meadow, S. (1993). Once is not enough: standards of well-formedness in manual communication created over three different timespans. *Language* 69, 683–715. doi: 10.2307/416883

Skehan, P., and Foster, P. (1997). Task type and task processing conditions as influenced on foreign language performance. *Lang. Teach. Res.* 1, 185–211. doi: 10.1177/136216889700100302

Skehan, P., and Foster, P. (1999). The influence of task structure and processing conditions on narrative retellings. *Lang. Learn.* 49, 93–120. doi: 10.1111/1467-9922.00071

Slobin, D., Hoiting, N., Kuntze, M., Lindert, R., Weinberg, A., Pyers, J., et al. (2003). "A cognitive/functional perspective on the acquisition of classifiers," in *Perspectives on Classifier Signs in Sign Languages*, ed. K. Emmorey (Oxfordshire, UK: Taylor and Francis), 271–298.

Streeck, J. (2008). Depicting by gesture. *Gesture* 8, 285–301. doi: 10.1075/gest.8.3.02str

Supalla, T. (1986). "The classifier system in American sign language," in *Noun Classes and Categorization 7*, ed. C. Craig (Amsterdam/Philadelphoa: John Benjamins), 181–214.

Swain, M. (1985). "Communicative competence: some roles of comprehensible input and comprehensible output in its development," in *Input in Second Language Acquisition* eds S. Gass and C. Madden (New York, NY: Newbury House), 235–253.

Taub, S., Galvan, D., Pinar, P., and Mather, S. (2008). *"Gesture and ASL L2 acquistion." Sign Languages: Spinning and Unravelling the Past, Present and Future.* Petropolis: Arara Azul.

Thumann, M. (2010). *Identifying Depiction in American Sign Language Presentations* (dissertation). Washington, DC: Gallaudet University.

Thumann, M. (2013). Identifying recurring depiction in ASL presentations. *Sign Lang. Stud.* 13, 316–349. doi: 10.1353/sls.2013.0010

Valli, C., Lucas, C., Mulrooney, K., and Villanueva, M. (2011). *Linguistics of American Sign Language: An Introduction*. Washington, DC: Gallaudet University Press.

Wilcox, S., and Wilcox, P. (1997). *Learning to See: Teaching American Sign Language as a Second Language*. Washington, DC: Gallaudet University Press.

Zwitserlood, I. (2012). "Classifiers," in *Sign Language. An International Handbook*, eds. R. Pfau, M. Steinbach, and B. Woll (Berlin: De Gruyter Mouton), 158–186.

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# Disability does not negatively impact linguistic visual-spatial processing for hearing adult learners of a signed language

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The majority of adult learners of a signed language are hearing and have little to no experience with a signed language. Thus, they must simultaneously learn a specific language and how to communicate within the visual-gestural modality. Past studies have examined modality-unique drivers of acquisition within first and second signed language learners. In the former group, atypically developing signers have provided a unique axis—namely, disability—for analyzing the intersection of language, modality, and cognition. Here, we extend the question of how cognitive disabilities affect signed language acquisition to a novel audience: hearing, second language (L2) learners of a signed language. We ask whether disability status influences the processing of spatial scenes (perspective taking) and short sentences (phonological contrasts), two aspects of the learning of a signed language. For the methodology, we conducted a secondary, exploratory analysis of a data set including college-level American Sign Language (ASL) students. Participants completed an ASL phonological- discrimination task as well as non-linguistic and linguistic (ASL) versions of a perspective-taking task. Accuracy and response time measures for the tests were compared between a disability group with self-reported diagnoses (e.g., ADHD, learning disability) and a neurotypical group with no self-reported diagnoses. The results revealed that the disability group collectively had lower accuracy compared to the neurotypical group only on the non-linguistic perspective-taking task. Moreover, the group of students who specifically identified as having a learning disability performed worse than students who self-reported using other categories of disabilities affecting cognition. We interpret these findings as demonstrating, crucially, that the signed modality itself does not generally disadvantage disabled and/or neurodiverse learners, even those who may exhibit challenges in visuospatial processing. We recommend that signed language instructors specifically support and monitor students labeled with learning disabilities to ensure development of visual-spatial skills and processing in signed language.

KEYWORDS

**sign language, second language (L2) acquisition, disability, neurodiversity, Attention-Deficit and Hyperactivity Disorder (ADHD), learning disabilities (LD), visuospatial processing, perspective-taking**

## Introduction

Consider a hearing, monolingual, English-speaking individual with a diagnosis of dyslexia learning a spoken second language (L2), such as Spanish or French, in a formal classroom setting in the United States. This student will likely have both a neuropsychiatric and academic record of impairment in the written and spoken modalities of language (Individuals with Disabilities Education Act, 2004). Based on this record, this learner may have specific modifications made to their coursework so that it is accessible, such as oral administration of test materials (Kormos, 2017b). In some cases, this record would even sufficiently permit them to waive institutionally administered requirements for world language coursework (Lys et al., 2014).

Now consider the same dyslexic learner in a signed language classroom. This student will likely have no record of their personal abilities in the context of the signed modality of language. There is scant research on hearing, atypical L2 sign learners (though see Singleton and Martinez, 2015), either working from a framework of disability or neurodiversity[1] (Singer, 1998; Bertilsdotter Rosqvist et al., 2020). Thus, there is little context to predict what unique experiences this learner, or any disabled[2] or neurodiverse learner with diagnoses affecting cognitive and/or linguistic processes, will face while specifically undergoing *signed* L2 acquisition. Students with a range of conditions, be they medically diagnosed or self-identified, may find themselves in need of support in language classrooms, but cohesive, empirically based recommendations for accommodations are nearly nonexistent. Demonstrating this unmet need, many language instructors have opted to collaborate amongst each other to develop and share their own personal strategies for working with disabled second language students (Kormos, 2017a), though existing discussion appears to be limited to spoken language settings. Disability services coordinators have even recommended taking signed language courses as an *alternative* to spoken language coursework as a form of accommodation in itself, likely reflecting misguided conceptions about signed languages (Arries, 1999). Researchers have posited potential modality effects on sign-naïve L2 learning (Quinto-Pozos, 2011; Chen Pichler and Koulidobrova, 2016) and, importantly, have noted signed modality features that might either impede *or* facilitate learning for individuals with processing challenges (Quinto-Pozos, 2014). Determining if and in what direction modality effects exist for atypical L2 learners could set precedent for signed language classroom accommodations, while also informing theory of modality and language.

The landscape of disability types and labels is complex, such as reference to non-discrete categories and the use of various approaches for diagnosis, including academic and psychological factors. In this introduction we highlight some of the complexity with disability categories and labels, with a focus on disabilities that are primarily cognitive in nature and may be particularly pertinent to learning (thus, excluding physical/motor disabilities, sensory disabilities such as blindness and deafness, and emotional or mental illness). First, we introduce general points about disability types and terminology, including how various labels are used by well-known diagnostic criteria. Then, we discuss disabilities affecting cognition in the context of language learning, including what we know from spoken language studies. As part of the landscape on this topic, we highlight the category of "learning disability," a contentious topic in the context of world language coursework, and its own complexity. Finally, we discuss psycholinguistic factors related to signed L2 learning, with an emphasis on factors that are shown to be challenges with the disability groups examined for this paper. The goal of the introduction is to provide the reader with information about the landscape of disabilities related to cognition, learning, and language and what we know about their relationships with language learning. For a detailed reference on how and which specific disabilities are potentially implicated as risk factors to second language learning, see Kormos (2017a).

Most existing discussion on the disability in second language learning is exclusive to spoken or written language and centers "learning disability," which is not a cohesive term. Colloquially, people often refer to wide range of disabilities as "learning disabilities," including those that technically fall into different diagnostic groups from specified learning disorders (Learning Disabilities Association of America, 2013a). Related phrases like "cognitive disability(s)" are likewise used at times as interchangeable umbrella terms for disabilities related broadly to learning, cognition, and language, including Attention-Deficit Hyperactivity Disorder (ADHD), autism, and even aphasia (Sims and Delisi, 2019). However, intellectual disability (the modern term for what was formerly labeled cognitive disability) is a specific medical label separate from learning disorders, which is indicated by diminished "intellectual functioning," challenges in "adaptive functioning," and an onset in early childhood (American Psychiatric Association, 2013). This label is also associated historically with low IQ, though this is no longer a diagnostic requirement per the most recent iteration of the DSM-5. At any rate, the coopting of labels such as "learning disability" and "cognitive disability" as umbrella terms appears to reflect an inclination to group disabilities like

1 That is, a framework of neurodiversity which includes but is not limited to diagnoses such as autism, dyslexia, ADHD, brain injuries, and personality disorders, as per both the original and other modern frameworks of neurodiversity (Singer, 1998; Bertilsdotter Rosqvist et al., 2020).

2 Here, we intentionally take after disability scholars and activists in following the Say The Word movement (Andrews et al., 2019), where we use identity-first language; i.e., *disabled people* versus *person with a disability*.

learning disorders, ADHD, language impairment, and autism together, despite the fact that there isn't an existing universal term encompassing these diagnoses.[3] Though maintaining the distinction of other diagnoses from specific learning disorders, Kormos (2017a) likewise includes ADHD, autism, and language impairment in their discussion of how learning differences affect second language learning processes, justified on the basis of impairment in both academic performances and language learning.

Technically, the most recent iteration of the Diagnostic and Statistical Manual, the DSM-5 (American Psychiatric Association, 2013), defines only one "Specific Learning Disorder" with potential subtypes in reading, writing, and mathematics (also referred to as dyslexia, dysgraphia, and dyscalculia, respectively).[4] Per the DSM-IV (American Psychiatric Association, 1994), these would have simply been referred to as "learning disorders," or "learning disabilities." Thus, much of the literature reviewed here, contemporary with the era of the DSM-IV, uses these terms (we maintain usage from source material when referencing terminology). Other sources may opt for the term "learning differences" to reference these diagnoses (Kormos, 2017a). Learning disorder diagnoses are unique in that they are predicated on an educational context. They are defined broadly, encompassing, essentially, any pronounced difficulty in one or more respective academic subjects (reading, writing, mathematics) that is unexplained by a separate disability or environmental factors. Despite changes in diagnostic criteria over time, any iteration of the label for learning disorders presupposes an element of "unexpectedness" (Kormos, 2017a; Schaywitz and Schaywitz, 2017) of the demonstrated academic performance based on factors such as overall intelligence, physical capabilities, and environment. "IQ-achievement discrepancies" were once even a core criterion of these diagnoses, though these guidelines are no longer in practice (Sparks, 2016). Here, we emphasize a relevant distinction from intellectual disability and general cognitive impairment encoded into learning disorder diagnoses: these labels are typically used for individuals who are deemed as having relatively "low" support and accommodation needs.[5]

3 It is worth noting that these *do* all fall under the umbrella of "neurodevelopmental disabilities" in the DSM-5, however (American Psychiatric Association, 2013).

4 Incidentally, none of the participants in the present study self-indentified with dysgraphia or dyscalculia; thus, we will not discuss these specific diagnoses in much detail.

5 We would like to acknowledge that many members of the disability community, especially the autistic community, find reference to terminology of "low" and "high" functioning and/or needs to be harmful (Bottema-Beutel et al., 2021); our reference to support needs reflects ways in which researchers and practitioners categorize these individuals. This performance may be contrary to true differences between individuals with learning and intellectual disabilities.

Given that literature on disability and language learning centers specific learning disorders, the nature of the diagnosis greatly affects the landscape of the types of participants included in this research. Namely, the sample populations are generally relatively high-achieving students, including in the present study, which is an important limitation to generalizability to keep in mind.

While there is a large body of research devoted to the psycho-linguistic underpinnings of specific learning disorders (especially dyslexia), diagnostic criteria for these labels are guided primarily by academic performance as assessed at an early age. Evaluations include review of academic records, behavioral interviews, and psychometric measures which are often performed within primary and secondary school systems by qualified counselors, teachers, and school psychologists (Learning Disabilities Association of America, 2013b). This is in contrast to a diagnosis like Auditory Processing Disorder (APD), for example, which is typically provided by an outpatient audiologist using specified auditory processing tasks of temporal processing, sound localization, and pattern recognition (American Speech Language Hearing Association, 2023). This is not to say that specific learning disorder diagnoses not rigorous or valid. Among thirteen disability categories, accommodations for both specific learning disorders and ADHD are equally protected by the Individuals with Disability Education Act (IDEA), and auditory processing disorder, for example, was recently determined by court decision as a protected disability by IDEA as well (E. M. vs. Pajaro Valley United School District, 2014). The process of diagnosis for specific learning disorders, though (especially for dyslexia), entails an assessment of poor reading and/or written language skills, hence their prominence in disability and language learning literature.

Specific learning disorders are of interest to language learning literature due not only to their inherent relationship to reading and writing skills, but their prevalence. Alongside Attention Deficit Hyperactviity Disorder (ADHD), they are among the most common neurodevelopmental disorders (American Psychiatric Association, 2013). Specific learning disorders and ADHD are also highly co-occuring. Thus, they both have received the bulk of attention in regard to disability in language learning literature, especially the dyslexic presentation of a specific learning disorder. Likewise, the labels "learning disorder," "dyslexia," and "ADHD" represent the most common diagnoses in our sample population.[6] Therefore, these diagnoses will be the focus of this literature review.

6 Much of the literature referring to "learning disability" or "learning disorder" appears to primarily focus on dyslexia; however, much of the referenced literature does not make a distinction between the types of learning disorder. Hence, the rest of this paper tends to refer to "learning disability" as referenced in the discussed literature. When a research finding specifically pertains to dyslexia and this is made explicit in the referenced text, the term "dyslexia" is used.

Schneider and Crombie (2003) emphasize the nature of dyslexia as a multi-modal construct which could impact levels of L2 learning beyond reading and writing, including "oral, auditory, kinesthetic, and visual" difficulties. Arries (1999) likewise cites "salient characteristics" of "learning disabled" students that may impact their L2 learning, including phonological processing issues, reading difficulties, memory impairments, anxiety, challenges with maintaining attention, and poor metacognitive skills for classroom learning. Here, Arries is using a more colloquial definition of "learning disability," including ADHD and even brain injuries as well as specific learning disorders like dyslexia. The DSM-V describes ADHD as a learning difficulty (though *not* a specific learning disorder), as opposed to its description as a behavioral disorder in previous iterations (Kałdonek-Crnjaković, 2018). It also specifies that invidiuals with ADHD have "reduced school performance and academic attainment" American Psychiatric Association, 2013). Kałdonek-Crnjaković (2018) discusses how features of ADHD could specifically impact language learning: inattentiveness may hinder incidental learning as well as novel word storage, retrieval, and coding, while impulsivity could impede high-level, pragmatic skills like conversational turn-taking. These suggestions are supported by the findings of Paling (2020), in which college-level students with ADHD self-reported significantly more negative experiences than a control group without ADHD in terms of language learning difficulty and progression.

Spoken language learning research on disability has primarily focused on auditory phonological measures. Thus, extrapolating findings to signed languages is not straightforward. In fact, the most recent legal definition of dyslexia in the United States invokes phonological processing difficulties as a reason dyslexic individuals may struggle with second language learning, but specifically in the auditory realm:

> "[Dyslexia is] most commonly due to a difficulty in phonological processing (the appreciation of individual sounds of spoken language), which affects the ability of the individual to speak, read, spell, and often, learn a second language."
>
> [Senate Resolution. 114th CONGRESS, 2nd SESSION ed, 2016, as cited in Schaywitz and Schaywitz (2017)]

However, research on dyslexia does analyze visual language processing in the form of *written* language. As referenced in the senate resolution above, the primary etiology for dyslexia is widely considered to be an auditory phonology based issue (American Psychiatric Association, 2013), but there is evidence in developmental literature that children with dyslexia also exhibit visual or visuospatial challenges (Valdois et al., 2004; Lipowska et al., 2011; Laasonen et al., 2012; Chamberlain et al., 2018). Valdois et al. (2004) argue that visual attentional challenges may be a secondary area of concern for characterizing different profiles of dyslexia. They explain that a atypical visual attentional patterns may, for example, drive distinctiveness in visual scanning behaviors and span while reading. To be clear, signed language structure is assuredly different from that of written language. The latter is two-dimensional code, while the former is three-dimensional, natural language. Still, the evidence of distinct visual processing challenges in dyslexic populations raises the question of whether such differences will be domain general and thus, affect signed language processing.

Though not examined in the context of language learning, developmental research also indicates that ADHD populations demonstrate specific challenges in visual processing. Children with ADHD show disrupted visual attention (Li et al., 2004), and in fact, may have more prominent challenges with attention in the visual modality versus the auditory modality (Lin et al., 2017). Furthermore, children with ADHD show impaired working memory in both visual and phonological (i.e., auditory) domains (Gallego-Martínez et al., 2018). Both verbal and non-verbal working memory impairments are hallmarks of language atypicality in children, and there is evidence that attentional impairments in these populations contribute to an inability to maintain, process, and synthesize linguistic information in short-term memory (Gillam et al., 2017). Given that these exact types of challenges are observed in ADHD populations, this raises the question of whether they similarly impact ADHD individuals' language learning processes, be that in the auditory or visual modality. Moreover, if challenges are more pronounced for this group in the visual modality as Lin et al. (2017) suggests, then it is worth investigating whether the visual modality of language yields specific detriments to ADHD learners.

There is even reference in practice to specific "learning disabilities" of visual processing in the (outdated) label of "non-verbal learning disability," which ostensibly encompasses challenges specifically in visuospatial perception and reasoning as well as "social-emotional" skills (Garcia et al., 2014). In part due to the controversial nature of this diagnostic label (which is not in the DSM-5)[7], findings are sparse and difficult to review, particularly in relation to language learning. However, research on these disabilities provides evidence of visuospatial working memory challenges that are parallel to the types of verbal working memory issues observed in dyslexic populations (Garcia et al., 2014). Relatedly, there is direct evidence from sign language research of how such challenges could affect native signed language acquisition. Quinto-Pozos et al. (2013) review the case of a deaf, child, signer of American Sign

7 It's important to note that though the diagnoses may be outdated per standard resources like the DSM, diagnoses may still be assigned by practitioners at their discretion; further, individuals provided with diagnoses in childhood that later become out of date will still maintain that diagnostic label and are able to receive services for it. This is especially important to consider in the context of how participants self-identify their diagnoses.

Language named "Alice," who, based on educational and psychological records, had a marked impairment in visuo-spatial processing which was not explained by her general intelligence, language fluency, or language experience. The case study affirmed this assessment of Alice, as she exhibited difficulty with production and perception of spatial devices in ASL, especially those requiring shifts in visual perspective. Alice's processing difficulties were remarkable since she was exposed to ASL from birth and attended a bilingual (ASL-English) school.

Similar visual-spatial challenges to Alice's have yet to be reported in adult hearing learners of a signed language. Such learners may not even be aware of underlying visuospatial weaknesses, especially given labels for such impairments aren't used ubiquitously. Without a label, these students may not have a history of accessing classroom-based accommodations with respect to visual processing, thus leaving them without any reference for accommodation practices in a signed language classroom. For example, a formally diagnosed dyslexic student may have already engineered a set of personalized meta-learning accommodations over the course of years (oral administration of instructions, alternative fonts for written materials, etc.). An individual with visual processing difficulties lacking official diagnosis would not be aware of similar accommodations that could aid their learning, such as: three-dimensional models in lieu of abstracting from two-dimensional photos, moving visual information closer to their visual field, and visually streamlined (uncluttered) course materials (Ho, 2020).

The processing of visual perspective is particularly important in signed language learning, due to the visual-spatial nature of signed language productions. When describing a spatial scene in American Sign Language (ASL), signers often describe that scene from their own perspective, which means that interlocutors have to engage in mental perspective shifts in order to correctly interpret the layout of the scene. Additionally, various studies have revealed differences between males and females on perspective-taking tasks; generally, males outperform females on such non-linguistic tasks (Tarampi et al., 2016; Hegarty, 2017). However, differences among genders have been shown to disappear when participants are given perspective-taking tasks while engaged in linguistic processing (Brozdowski et al., 2019; Secora and Emmorey, 2020).

The bulk of research on even well-documented disabilities like dyslexia and ADHD, including that reviewed thus far, primarily concerns children, especially school-aged populations. As is the case with ADHD, characteristics of individuals in diagnostic groups might change as they age (Kormos, 2017a). There is mixed evidence as to whether and how visuospatial challenges persist into adulthood, and thus, would be relevant to an adult L2 learner. Bacon et al. (2013) find that dyslexic adults only performed worse than control groups on the reverse condition of a visuospatial memory task, a disadvantage remedied by explicit instruction. The authors argue that this suggests difficulty with executive function, but not visuospatial processing *per se*. Likewise, Łockiewicz et al. (2014) find that adults with dyslexia perform on par with control groups on 2D and 3D versions of a mental rotation task. These results, then, do not support sustained visual challenges in adult dyslexic populations.

In contrast, in an online measure of language processing, Armstrong and Muñoz (2003) find that adults with ADHD exhibit a prolonged "attentional blink" (the lag needed between two successive, rapid visual targets—e.g., alphabetic letters— to successfully identify both) compared to adult controls without ADHD. The ADHD group additionally, regardless of the lag in two targets, never reached performance commensurate with that of their performance on a single-target condition, while the control group did. Furthermore, the ADHD group tended to report targets that did not appear on screen in the trial, implying entirely failed perception that led to supplied guesses, where the control group would incorrectly identify stimuli actually preceding or following the target on screen. Finally, the ADHD group had an "unstable gaze" characterized by more eye movements overall, supporting the indication of non-perception errors.

Laasonen et al. (2012), though, only finds a prolonged attentional blink for dyslexic adults, and not ADHD adults, compared to neurotypical controls. Likewise, there was no disadvantage for the ADHD group on a field of vision (Useful Field of View) or visual attention capacity (Multiple Object Tracking) task, but the dyslexic group had longer response times on the former. By way of explaining the lack of underperformance for the ADHD group, Laasonen et al. report that ADHD is a "multifactorial and heterogeneous disability," and thus, number of and degree of symptoms that implicate cognitive issues may vary between individual cases, both in type and degree. Supporting this conclusion, Nilsen et al. (2013) find that ADHD adults with higher-severity symptoms (as determined by a standardized diagnostic scale) made more eye movements to distractors in a communicative perspective-taking task compared with adults with lower-severity symptoms. However, importantly, accuracy in the task itself was not affected by symptom degree.

In summary, studies of adult dyslexic and ADHD populations reveal the potential for sustained visuo-spatial processing challenges from childhood, especially in the temporal domain, but presentation may vary by the measure used and by individual performance. Both dyslexic and ADHD adults may show poor rapid visual processing, and multiple studies provide evidence of unstable eye gaze in adults with ADHD. The non-perception errors exhibited by individuals with ADHD in Armstrong and Muñoz (2003) exemplify a potential consequence of deficient temporal visuo-attentional mechanisms to online language processing, where portions of the linguistic signal may not be perceived at all. While

Laasonen et al. (2012) do not propose a specific underlying mechanism, they show dyslexic adults exhibit temporal visual processing differences using the same attentional blink task, resulting in lowered performance. Especially as the rigor and expected receptive fluency in a language learning environment increases, issues with temporal processing could pose challenges to students' understanding of the linguistic signal. It's further worth noting that the differences between neurotypical and disabled groups in these studies were found in a controlled experimental setting, where distractions would be at a minimum. This setting may not be representative of real-life classrooms, which have more environmental variability. Finally, while medication can sometimes alleviate visual attention difficulties in ADHD groups, some visual-processing challenges appear to be medication resistant (Maruta et al., 2017), and there are no such standardly used medications for dyslexic or otherwise learning-disabled groups. For both these reasons, one can't assume that either accommodation or medication will completely alleviate language learning challenges caused by problems with visualspatial processing in these groups.

While the previously reviewed studies provide insight into the cognitive profiles of dyslexic and ADHD groups, the question remains as to whether particular cognitive challenges will impact overall language learning outcomes in a classroom setting. In one of the few existing studies of disabled second language learners, Sparks et al. (2008) directly compare public high school students in Spanish language classrooms who either have a diagnosis of "learning disability" (LD) or ADHD. Diagnoses for students in each group were formally administered by appropriate authorities, per United States federal guidelines. These two groups were compared with an additional set of peers lacking either diagnosis, who were divided by the researchers into either "high-achieving" or "low-achieving" groups for purpose of analysis. The achievement groups were determined by teacher recommendations (for "good L2 learners" and "poor L2 learners") and the final grades of the students in the class, where those with a B or higher were in the high-achieving group. It's important to note that these comparison groups are not equal (i.e., there aren't "low-achieving" and "high-achieving" divisions for the LD and ADHD groups). The intent of the study was in part to determine whether poor language learners with disabilities are distinct from generally poor language learners without diagnoses, thus implying the need for specialized accommodations (as opposed to general supportive language learning practices in-classroom, for example).

The results for the Sparks et al. (2008) study were as follows. For L1 and L2 literacy measures as well as L2 proficiency measures, high-achieving students performed significantly better than low-achieving and LD students, but not ADHD students. However, high-achieving students did outperform ADHD students, as well as low-achieving and LD students, on the MLAT (Modern Language Aptitude Test), the L2 aptitude measure that was used for the study. ADHD students performed significantly better than LD students on all L2 linguistic tasks (e.g., word decoding, pseudoword decoding, spelling) and better than low-achieving students on all but one. Overall, there were no group differences between low-achieving and LD students on any measures. Sparks et al. interpret the fact that the non-disabled "low-achieving" and LD groups show no group differences as an indication of, essentially, equally deficient language learning capabilities and cognitive-linguistic skills. We find it worth noting, though, that especially in a group of LD students with formal diagnoses and accommodations to support their learning, one wouldn't expect students labeled as learning disabled students to perform categorically like "poor learners;" variation should be expected within-group, as well. The results also provide evidence that ADHD students may not share this risk for language learning difficulties. To this point, the authors note the heterogeneity in individuals with ADHD, which was reflected in how performance in this group varied greatly by individual and task. In other words, they emphasize that the ADHD participants' performance as a group may not reflect individual challenges; this commentary echoes the findings of Laasonen et al. (2012), who also indicated that individual differences in ADHD participants may mask overall group differences.

The overview presented thus far on disability categories and (language) learners provides a backdrop for considering L2 hearing learners of a second language, primarily in *spoken* language learning. In addition to the fact that the indicated disability groups here may present specific visual processing challenges, signed language classrooms need consideration due to their well-established popularity. American Sign Language (ASL) is an increasingly popular choice for college students seeking to fulfill post-secondary language requirements in the United States. According to the Modern Language Association survey of foreign language enrollment in higher education, enrollment in ASL courses increased by 434 percent between 1998 and 2002, growing from 11,420 to 60,781 students (Welles, 2004). By 2013, ASL became the third most studied language in U.S. higher education, following Spanish and French (Looney and Lusin, 2019). Disabled students are also a growing minority in higher education, generally (Sanford et al., 2011), increasing the chance that students in language classrooms have a disability affecting their learning experience. The general population of students has been shown to gravitate to signed language classrooms due to assumptions about the "ease" of learning signed languages (Jacobs, 1996). We speculate that disabled students could be particularly attracted by the misleading proposition that signed languages are more adaptable to their learning difficulties, which is supported by formal recommendations made to pursue signed language classrooms as alternatives to spoken language coursework (Arries, 1999).

In a more positive vein, we also suggest disabled learners could be drawn to (and feel welcomed in) signed language learning spaces due to the Deaf community's proximity to disability communities.

The majority of adult ASL learners are what Chen Pichler and Koulidobrova (2016) define as M2L2 learners— L2 learners also acquiring that second language in a non-native modality. Among possible modality-driven learning effects for this group, Chen Pichler and Koulidobrova describe the challenge of acquiring a new phonological inventory within a simultaneously acquired, also non-native system of visual phonology. Of note here is the simultaneous vs. sequential arrangement of signed and spoken phonological parameters, which may in itself drive differences in L2 learning (Quinto-Pozos, 2011). Grammatical use of space, they add, such as pointing, spatial agreement on verbs, and classifiers (gesture-like signed language devices used to indicate movement, shape, and size *via* language-specific handshape constructions), also necessitates that sign-naïve individuals learn to operationalize their gestural space according to signed language grammar. Evidencing the difficulty of spatial grammar acquisition, classifier constructions in particular are shown to challenge M2L2 signers (Boers-Visker and Van Den Bogaerde, 2019); these constructions are also late-acquired in native signing (Morgan et al., 2008) and shown in at least one case study to be difficult for a visuospatially impaired native signer (Quinto-Pozos et al., 2013). This raises the question of whether M2L2 learners with similar visuospatial challenges will also encounter additional difficulty in spatial grammar, especially classifier constructions.

A handful of studies have directly assessed the relationship between cognitive factors like visuospatial or auditory memory and M2L2 signed language learning specifically. Williams et al. (2017) investigate cognitive-linguistic measures administered in the auditory L1 modality in relation to L2 signed language learners' ASL vocabulary and self-rated proficiency tested at the beginning and end of one semester of ASL instruction. The predictive measures included a forward and backward version of a digit span task, an English vocabulary test, and an English phonetic categorization task. Interestingly, Williams et al. find that the English vocabulary and phonetic categorization measures, and not the verbal memory measures, predicted ASL vocabulary growth and self-rating.

Martinez and Singleton (2018, 2019) also conducted a series of studies looking at factors for signed vocabulary learning in hearing, non-signing populations. In the first study (2018), the authors implement a series of short-term memory tasks, contrasting those that include sign or sign-like stimuli with those that contain visual stimuli which are not sign-like (for example, videos of body movements vs. patterns of shapes). The first set of these tasks were referred to as movement short-term memory (STM) tasks, which the authors hypothesized would be more related to sign learning than the other types of STM tasks due to the "encoding and binding of biological motion." They find that all three administered measures of movement STM and both measures of visuospatial STM positively related to hearing non-signers' performance on a sign learning task. Additionally, the visuospatial memory tasks, which, in contrast to two of the movement tasks, did not resemble linguistic properties of signed language, accounted for variance in the sign learning task beyond that accounted for in the movement memory tasks. The authors take the latter finding to indicate the importance of perceptual-motor processes related to the visuospatial modality generally, rather than phonological properties of signed language.

Accordingly, Martinez and Singleton (2019) investigate both domain-general and modality-specific factors related to sign and word learning. In addition to investigating working memory and short-term memory *via* span tasks, they explore the effect of both crystallized and fluid intelligence. Here, crystallized intelligence refers to the learner's pre-established familiarity with facts and processes, where fluid intelligence refers to the individual's capacity to navigate and solve novel situations (Martinez and Singleton, 2019). These measures were obtained *via* a series of tasks testing general knowledge, pattern recognition abilities, and English vocabulary. They find that fluid intelligence related to both sign and word learning; however, the effects of phonological short-term memory (P-STM) were modality-specific (i.e., spoken P-STM related to word learning, and signed P-STM related to sign learning). The authors did not find a significant effect for Working Memory Capacity (WMC) as a whole on either sign or word learning. This finding is unexpected due to the fact that STM is a sub-component of WMC. The authors suggest that between the variance accounted for by both fluid intelligence, a skill highly related to WMC, and the P-STM tasks, the effect of WMC was potentially obscured. The influence of both WMC and P-STM on sign learning processes is particularly relevant to the present study due to the ubiquitous presence of challenges with working memory in target disability population groups. The two studies from Martinez and Singleton (2018, 2019) affirm that individual capabilities in the visuospatial short-term memory subcomponent of working memory are, in fact, at issue for signed vocabulary learning.

Due to the demonstrated impact of both modality-general and modality-specific factors on signed language learning, it is possible that M2L2 signers with disabilities that entail deficient general cognitive or visual processes will be negatively impacted in sign learning processes. Considering the literature reviewed on ADHD and dyslexic individuals specifically, potential areas of interest include visuospatial working memory, rapid visual processing, and inhibiting attention to visual distractors. However, it's also possible that the modality of signed language may be beneficial in general to many different kinds of atypical learners, particularly in comparison to L2 acquisition of spoken language. Quinto-Pozos (2014) predicts that for signed language users with compromised processing, some difficulties may include comprehension and production of complex forms with simultaneous morphology, rapid fingerspelling comprehension, and managing perspective shifts with respect to the signing space. Some benefits, though, may be the increased size of and visual access to articulators as well as slow signing speed in comparison to speech rates.

Singleton and Martinez (2015) provide, to the authors' knowledge, one of the only existing studies explicitly designed to investigate the experience of M2L2 learners with disabilities. Singleton et al. (2019) for a review of atypicality with respect to signed language learning in adolescence and adulthood. The study was conducted at a private United States high school for academically gifted students with language and learning disabilities (here, used in a more general sense, encompassing disabilities like ADHD as well as specific learning disorders). The authors conducted interviews with students taking either Spanish or ASL. They also collected student self-ratings of difficulty for learning the language for which they were enrolled. Some students reported a positive qualitative experience with ASL in relation to their disability, including one student with both dyslexia and ADHD:

> "Yeah… it makes your eyes more focused. Like, maybe this is just for me. But like, obviously, dyslexia is a big part of my life, "cause this is what I have to live with for the rest of it. But like I said before, people on dyslexia they pick up on the small things. And people on ASL, like sign language, you have to look at the small things. And it's helped my focus. Because I have dyslexia and ADD. So, it helps me focus better. Like paying attention, 'cause I have to pay attention to them to understand what they're saying." (Singleton and Martinez, 2015)

They also found that students with ADHD, for example, on average rated Spanish as more difficult than ASL. However, the students in the ASL courses also had higher scores on IQ measures, so this could be explained by a cognitive advantage in the ASL student group. Extrapolating from the findings on the ratings, then, must be done with caution. However, the consistent, positive attitudes students held about their learning experience in ASL classrooms are informative. It's also valuable that these reports come directly from the experiences of the population of interest. At minimum, these students did not report a negative experience with respect to their diagnoses, in contrast to the findings of Paling (2020), who found that students with ADHD self-reported *negative* experiences with spoken language learning. In the above excerpt, the student goes so far as to describe the visual-manual mode of language as a benefit, rather than an obstacle, to their language learning experience.

In summary, there are aspects unique to the visual modality of signed language that may have negative or positive implications for M2L2 signed language learners. Additionally, cross-modal cognitive factors from learners' first languages, domain-general skills like fluid intelligence, and modality-specific perceptual and memory processes are all potentially implicated in sign learning (Williams et al., 2017; Martinez and Singleton, 2018, 2019). There is evidence that learners with certain diagnoses, especially ADHD and dyslexia, may show challenges in these domains, raising the question of whether they are at risk in a signed language learning setting compared to peers lacking these diagnoses.

We have outlined various ways in which language learners with disabilities encounter challenges with language processing, and phonological features of language have been investigated repeatedly. Specific to signed language, the processing of perspective has been shown to be particularly challenging for all learners (Brozdowski et al., 2019; Secora and Emmorey, 2020). This study investigates whether hearing L2 ASL signers with disabilities related to cognition, learning, and language perform differently than peers reporting no such diagnoses on three tasks: (1) a signed phonological discrimination task; (2) an ASL-based perspective-taking task; and (3) a non-linguistic perspective taking task. Between these three tasks, we are able to compare participants' perception of: (1) phonological components of signed languages, and (2) visuospatial processing skills in both a linguistic and non-linguistic mode of delivery. For individuals with specific learning disorders in particular (especially dyslexia), there is ample evidence of phonological processing challenges in the *spoken* modality of language. Including a signed phonological processing measure allows us to assess whether this is the case in the signed modality, as well. On the other hand, there is at least one documented case of a deaf adolescent native signer with visuospatial processing challenges that negatively affects their processing of perspective-taking constructions in ASL (Quinto-Pozos, 2011). Perspective-taking has also been shown to present challenges to deaf L2 signers, as well (Brozdowski et al., 2019; Secora and Emmorey, 2020). In other words, these measures probe a uniquely challenging aspect of sign learning, which may be even more difficult for learners with visuospatial processing difficulties, as are documented in our target disability populations.

Our participant pool is composed of students from beginning and intermediate courses of an ASL program at a large, public, university. The majority of students in these courses (over 75%) during the semesters we collected data participated in data collection, which contributes to the ecological validity of the collected data. In other words, the data set is highly representative of typical ASL students at the points of time that data were collected. This is true, as well, for the range of disabilities reported by participants. As such, we did not actively recruit students from any disability category, which is reflected in the uneven distribution of participants across neurodiverse categories.

TABLE 1 Participants by diagnosis type, total.

| Diagnostic category | Participants ($n = 166$) |
|---|---|
| No diagnosis reported | 131 |
| Visual | 5 |
| ADD/ADHD | 10 |
| LD | 5 |
| Other* | 9 |
| Multiple** | 6 |

*Including Dyslexia ($n = 3$), Auditory Processing Disorder ($n = 2$), Language Impairment ($n = 2$), Narcolepsy ($n = 1$), and Concussion ($n = 1$).
**Including LD + ADD ($n = 3$), LD + Auditory Processing Disorder ($n = 1$), LD + Dyslexia ($n = 1$), LD + Visual ($n = 1$).

Most literature reviewed here is limited to only specific learning disorders (especially dyslexia) and ADHD. Here, we consider any disability reported that would primarily affect language, cognition, or learning, excluding categories such as deafness, mobility disabilities, and emotional or psychological disabilities. In this approach, we hope to contribute to establishing a lacking precedent in analyzing disability as a part of L2 acquisition research. Moreover, we hope that in including participants who directly correspond to the types of disabled students in ASL classrooms, our project is directly informative to practice. We seek to address which, if any, components of signed language and visual-spatial processing disadvantage L2 learners who are disabled and/or neurodiverse.

# Materials and methods

## Participants

Participants were hearing college students ($n = 166$, 134 female, 29 male, 3 N/A) enrolled in either beginners' (ASL I, $n = 43$) or intermediate (ASL III, $n = 123$) university ASL courses at the same public university. Students in these courses received credit for participating in a research experiment. Students also had the option of attending a colloquium presentation and writing a summary of that presentation if they did not want to participate in the research experiment. Some students did not participate in any way (either *via* completing the research experiment or attending the colloquium presentation), in which case they were not awarded credit for this aspect of the course. The participants in this analysis represent students in the ASL program who elected to fulfill this research credit by participating in the present study.

Prior to administration of the experimental tasks, all participants filled out a Qualtrics data form regarding demographic information, relationships to the Deaf community, and language backgrounds. Participants also self-reported diagnoses from a provided list, with the option to submit additional diagnoses not provided. Thirty-five participants reported one or more diagnoses (Table 1). The diagnoses listed in the survey consisted primarily of those that might belong the neurodivergent community, such as autism, ADHD, learning disability/dyslexia, traumatic brain injuries, and auditory processing disorders (Singer, 1998; Bertilsdotter Rosqvist et al., 2020). Language and speech disorders were also included. The goal was to target diagnoses that represented individuals who primarily had learning, language, and processing difficulties. Motor disabilities, for example, were not included, as well as mood, emotional, and personality disorders. Participants were asked to report visual disabilities, which were included in the analysis.

While disability was not among the initial factors that motivated the data collection for this study, nearly 22% of respondents identified with one or more disabilities. Due to this notable percentage, we were compelled to engage in this exploratory analysis of the role of disability in signed language learning. As such, we did not purposefully recruit students with disabilities (of any category), and the results is that categories of disability have a variety of participants for the analysis.

## Procedure

Participants locally participated in the experiment in a single, hour-long session. Administration of tests was provided in either English or ASL by a trained research assistant. Data collection occurred as part of research projects that were carried out in 2012 and 2018–2020; the data from the two time periods are compared statistically in Sections ASL-PTCT and NL-PTT. The order of the tasks was randomized for each participant. Informed consent was received from all participants.

## Materials

### The American sign language discrimination test

The American Sign Language Discrimination Test (ASL-DT) is a phonological discrimination task administered online with 48 items consisting of videos of paired sentences in ASL (Bochner et al., 2011). After viewing the temporarily displayed videos, participants report whether the sentences are the same or different by selecting an appropriate button. The sentences may be the same or differ on five morphophonological-parameters on a single sign: handshape, orientation, location, movement, and complex morphology, where complex morphology refers to contrasts in directionality, numerical incorporation, noun classifier usage, and verb inflection. Each item consists of two *pairs* of sentences, and test-takers provide a judgment of the similarity or difference of the sentences. There are eight stimuli pairs for each of the six morphophonological contrast categories, including the *same* condition in which there is no difference between the two sentences in each stimulus pair. There are five contrast conditions, and one *same* condition. To reduce chance performance, participants must respond correctly to each pair in the item.

Three Deaf native signers produced the ASL sentences in the video. Two were male and one was female. The first male always signs the first sentence, and one of the other two signers produce the comparison sentence that follows. Non-contrastive variation between the signers, such as phonetic articulatory differences (which do not alter the meaning of the sentence), was included in the recordings to increase the difficulty of the task.

Only participants in the later data collection session completed the ASL-DT ($n = 101$). Thus, there were 66 participants in the earlier data collection session which did not complete the ASL-DT. Only data on overall accuracy (in the form of a percentage correct on all items) and confidence intervals of the final score are provided for the test-takers, thus, these are the only measures we have accessible to analyze.

### The American sign language perspective-taking comprehension test

The American Sign Language Perspective-Taking Comprehension Test (ASL-PTCT) consists of 20 items in which the participant views a video of a classifier description in ASL of two objects in relation to each other, then selects the appropriate picture of the corresponding items from four answer choices (Quinto-Pozos and Hou, 2013). The answer choices differ both in how the described objects are *arranged* and *oriented* with respect to each other within-trial. *Arrangement* refers to whether one object, for example, is set up to the left or right of the other (both objects always face the same direction). *Orientation* refers to the orientation of the object in its position, for example, whether a dog is standing up or laying on its side. The answer choices also vary across trials by the shift in perspective required between the stimulus and the answer choices. Namely, each of the five blocks of the experiment has a different degree of rotation from the original perspective of the photo, increasing in 45° increments from 0° in the first block (0°, 45°, 90°, 135°, 180°).

The prompt ASL video was also filmed either from the opposite perspective (the typical 180-degree shift in viewpoint in signing) or a side-by-side perspective (the signer shares a perspective with the participant), which allows the test-taker to have two views of the signer and the signs for the test. One of two versions of the ASL test was administered to each participant, each with a different model signer. All videos were filmed with a fluent, Deaf ASL signer as the signing model. Accuracy and response time are measured for each item. See https://osf.io/cnhq7/?view_only=7531d3529b1d453ebf04e93329321963 for all of the materials in the ASL-PTCT task.

### The non-linguistic perspective taking test

The Non-Linguistic Perspective-Taking Test (NL-PTT) is structured like the ASL-PTCT, but uses still images of objects arranged in relation to each other as the stimulus prompts rather than videos of signed language describing the same scenes. Each of these stills stays on the screen for a total of 3 s at the beginning of the trial. Again, participants must select the correct answer choice from four photos that corresponds to the arrangement they saw in the prompt, where the arrangements and orientations between the objects in each answer choice are different, and the perspective shifts vary by block. For example, below, the participant sees a toy dog on its side facing a standing toy human in the prompt stimulus. The correct answer choice A, which matches the arrangement in the prompt stimulus but is viewed from a 45 degree shift in perspective. All of the other answer choices show the dog in an incorrect orientation with respect to the human.

All participants took both the ASL-PTCT and NL-PTT. See https://osf.io/7z4g5/?view_only=00085ff216164d14bcdc79e3e47314cc for a full demonstration of the NL-PTT task.

## Analysis

The method for the study was a secondary data analysis on the existing dataset. Data was analyzed in R using the following packages: tidyverse, lme4, sandwich, lmerTest, and effectsize.

For the purposes of the analysis, the participants who reported one or more diagnosis were assigned to the *neurodiverse* group, while those without a reported diagnosis were assigned to the *neurotypical* group. The ASL-DT was analyzed using A $2 \times 2$ ANOVA with total ASL-DT score per participant as the dependent variable and course level and neurotype as independent variables.

Response time and item accuracy in the perspective-taking tasks were analyzed using series of linear and generalized linear mixed effects regression models, respectively, estimated *via* maximum likelihood methods. Each model had random effects for item and participant. Fixed effects included a group for neurotype, sex, course level, and item perspective (ASL only).

Furthermore, models were run where diagnostic statuses were coded individually into groups, rather than by overall assignment to a neurotype. The categories were as follows: Neurotypical (no diagnosis reported), Visual Impairment, ADD/ADHD, Learning Disability (LD)[8], Other (including Auditory Processing Disorder, Concussion, Dyslexia[9],

8 It is worth nothing, again, that the definition of "Learning Disability" is somewhat vague and may be used different colloquially to refer to a range of disabilities, while in research and practice, it has been used to refer very specifically to reading, writing, and mathematical disabilities. We chose to follow the reports provided to us by participants.

TABLE 2 Participants by disability type, ASL-DT.

| Diagnostic category | Participants ($n = 91$) |
|---|---|
| No diagnosis reported | 70 |
| Visual | 2 |
| ADD/ADHD | 5 |
| LD | 4 |
| Other* | 8 |
| Multiple** | 2 |

*Including Dyslexia ($n = 3$), Auditory Processing Disorder ($n = 1$), Language Impairment ($n = 2$), Narcolepsy ($n = 1$), and Concussion ($n = 1$).
**Including LD + ADD ($n = 2$).

Narcolepsy, and Language Impairment), and Multiple. While these categories are not ideal or necessarily homogenous, we are limited by the relatively small number of diagnoses reported, and the responses as provided by the participants.

Wald confidence intervals were obtained for each regression factor; tests were set at 0.05 level of significance and all *p*-values were adjusted using the Holm correction. We report Odds-Ratios for the logistics regression analyses.

# Results

## ASL-DT

Seven of the participants' ASL-DT scores could not be recovered and three were indeterminate, thus $n = 91$ for the ASL-DT analysis, 21 of which identified one or more diagnoses (Table 2). Additionally, five outliers (all in the ASL III group) were removed from the analysis, based on the fact that their score was further than two standard deviations from the mean. There was a main effect for course level ($F_{1,86} = 18.80$, $p = 0.00$, partial eta-squared = 0.19), where ASL III students (M = 52.67, SD = 3.45, $n = 48$) had higher percentage accuracy scores than ASL I students (M = 49.08, SD = 4.16, $n = 38$). Neurotypical students outperformed neurodiverse students, but this difference did not reach significance.

## ASL-PTCT

Four participants' ASL-PTCT data could not be retrieved, thus $n = 162$ for the ASL-PTCT analysis, 35 of which identified one or more diagnosis (no individuals reporting a diagnosis were missing from the data set, so the breakup is the same as the general dataset). Summary data are reported overall in Table 3 and by diagnostic category in Table 4. Initial regression analyses revealed no significant effects of time period of the data set (i.e., the 2012 or 2018–2020 session of data collection) or test version on accuracy or response time, so these factors were removed from further models in the ASL-PTCT analysis, so that these groups were collapsed. The linear model found no significant main effects for group (disability category), sex, course level, or item perspective. The logistic model found a significant main effect for item perspective (OR = 0.51, CI = [−0.91, −0.43], $p < 0.001$), where opposite perspective (M = 0.64, SD = 0.48) items were less accurate than side-by-side perspective items (M = 0.75, SD = 0.43). A main effect for sex was also found (OR = 1.92, CI = [0.19, 1.19], $p = 0.05$), where males (M = 0.77, SD = 0.42) were more accurate than females (M = 0.68, SD = 0.47). No interaction effects were found.

Next, the same models were run with diagnoses coded by group. The logistic model again found a significant main effect for item perspective (OR = 0.51, CI = [−0.91, −0.43], $p < 0.001$). No other effects were found.

## NL-PTT

The same models as above were conducted. All participants were available, with 35 participants identifying as having a relevant disability. Summary data are reported overall in Table 5 and by diagnostic category in Table 6. Interestingly, there was a marginally significant main effect for data set on reaction time [$F_{(1,158.3)} = 5.7608$, CI = [−1,724.30, −174.08], $p = 0.05$], such that the data collected in 2012 set had a longer response time (M = 6,092.07 ms, SD = 3,597.52 ms) than the data from 2018 to 2020 (M = 4,848.75 ms, SD = 3,205.85 ms), so this factor was not removed for the NL-PTT (i.e., it was included in the statistical analyses as a factor). There was a main effect of sex on response time [$F_{(1,158.3)} = 8.81$, CI = [−2,226.77, −445.39], $p = 0.01$], such that the males (M = 4,026.758 ms, SD = 2,157.052 ms) were faster than females (M = 5,649.40 ms, SD = 3,591.408 ms).

The logistic model found a main effect for sex (OR = 2.06, CI = [0.32, 1.13], $p = 0.002$), where males were more accurate (M = 0.80, SD = 0.40) than females (M = 0.711, SD = 0.45). There was also a main effect of group (OR = 0.60, CI = [−0.86, −0.15], $p = 0.02$), where disabled participants (M = 0.67, SD = 0.46) were less accurate than the neurotypical group (M = 0.74, SD = 0.44).

Finally, the models were once again run with diagnoses separated by groups rather than as a single binary variable. A main effect for sex was once again found in the main linear model [$F_{(1,154.4)} = 9.36$, CI = [−2,308.55, −505.55], $p = 0.02$] and in the logistic model (OR = 2.04, CI = [0.31, 1.11], $p = 0.004$). Additionally, there was a main effect for the learning disability group (OR = 0.32, CI = [−1.95, −0.34],

9 It is interesting that these individuals identified Dyslexia and not Learning Disability, as any definition of Learning Disability should include Dyslexia. However, again, we chose to follow the reports provided to us by participants.

TABLE 3 Summary descriptive statistics for ASL PTCT, overall.

| Group | | Participants ($n = 163$) | Number Items | Mean RT (ms) | SD RT (ms) | Mean proportion correct | SD Proportion correct |
|---|---|---|---|---|---|---|---|
| Data Set | | | | | | | |
| | Old | 62 | 1,234 | 7,465.04 | 5,098.09 | 0.70 | 0.46 |
| | New | 101 | 2,020 | 6,661.95 | 4,192.06 | 0.69 | 0.46 |
| ASL Level | | | | | | | |
| | ASL I | 43 | 860 | 6,554.96 | 4,527.35 | 0.69 | 0.46 |
| | ASL III | 120 | 2,394 | 7,114.40 | 4,581.27 | 0.70 | 0.46 |
| Sex | | | | | | | |
| | Female | 131 | 2,614 | 7,105.40 | 4,652.29 | 0.67 | 0.47 |
| | Male | 27 | 540 | 6,353.866 | 3,750.239 | 0.77 | 0.42 |
| | N/A | 3 | 80 | 6,787.288 | 7,073.460 | 0.88 | 0.32 |
| Neurotype | | | | | | | |
| | Neurotypical | 128 | 2,554 | 7,007.07 | 4,604.19 | 0.71 | 0.45 |
| | Neurodiverse | 35 | 700 | 6,820.40 | 4,458.40 | 0.65 | 0.47 |

TABLE 4 Summary descriptive statistics for ASL PTCT by diagnostic category.

| Disability category | Participants ($n = 163$) | Number Items | Mean RT (ms) | SD RT (ms) | Mean proportion correct | SD proportion correct |
|---|---|---|---|---|---|---|
| No diagnosis reported | 128 | 2,554 | 7,007.07 | 4,604.19 | 0.71 | 0.45 |
| Visual | 5 | 100 | 5,746.87 | 3,503.69 | 0.63 | 0.48 |
| ADD/ADHD | 10 | 200 | 8,157.93 | 5,760.95 | 0.71 | 0.45 |
| LD | 5 | 100 | 7,596.68 | 4,724.90 | 0.50 | 0.50 |
| Other* | 9 | 180 | 5,701.30 | 3,350.83 | 0.70 | 0.46 |
| Multiple** | 6 | 120 | 6,498.98 | 2,995.51 | 0.63 | 0.49 |

*Including Dyslexia ($n = 3$), Auditory Processing Disorder ($n = 2$), Language Impairment ($n = 2$), Narcolepsy ($n = 1$), and Concussion ($n = 1$).
**Including LD + ADD ($n = 3$), LD + Auditory Processing Disorder ($n = 1$), LD + Dyslexia ($n = 1$), LD + Visual ($n = 1$).

$p = 0.04$) and a marginal effect of the multiple disabilities group (OR = 0.37, CI = [−1.72, −0.25], $p = 0.053$), where each group was less accurate (M = 0.55, SD = 0.50; M = 0.61, SD = 0.49) than the neurotypical group (M = 0.74, SD = 0.44).

## Discussion

In this study, we compared the performance of neurodivergent and neurotypical college-level ASL learners on a signed language phonological discrimination task as well as both a non-linguistic and a linguistic (ASL) version of a perspective-taking task. We sought to investigate whether individuals in the neurodivergent group were disadvantaged by visual-spatial processing in linguistic and non-linguistic contexts.

There was a main effect for group (disability vs. neurotypical) on accuracy, where neurotypical students outperformed disabled students, in the non-linguistic version of the perspective-taking task only. Similarly, there was an effect for the learning disability group and a marginal effect for the multiple diagnoses group in the models comparing disability groups, where both of these groups performed more poorly than the other diagnostic group, including the neurotypical group. All multiply diagnosed students reported "learning disability"[10] as one of their diagnoses. Students who self-identified as learning-disabled and multiply diagnosed were

10 It is worth noting, as stated earlier, that "learning disability" technically is used to refer to specific disabilities in reading, writing, and math (e.g., dyslexia, dysgraphia, dyscalculia); however, colloquially, people may use this to refer more generically to include other disabilities. Thus, without specific details, it's not clear what participants meant by reporting either "learning disability" or "dyslexia" without reporting the other option or further specifying their diagnosis, in the first case.

TABLE 5 Summary descriptive statistics for Non-linguistic PTT, overall.

| Group | | Participants ($n = 166$) | Number Items | Mean RT (ms) | SD RT (ms) | Mean proportion correct | SD proportion correct |
|---|---|---|---|---|---|---|---|
| Data Set | | | | | | | |
| | Old | 65 | 1,300 | 6,092.07 | 3,597.52 | 0.75 | 0.44 |
| | New | 101 | 2,020 | 4,848.75 | 3,205.85 | 0.71 | 0.45 |
| Sex | | | | | | | |
| | Female | 134 | 2,680 | 5,649.40 | 3,591.408 | 0.71 | 0.45 |
| | Male | 29 | 580 | 4,026.75 | 2,157.05 | 0.80 | 0.40 |
| | N/A | 3 | 60 | 3,971.81 | 1,692.50 | 0.79 | 0.40 |
| ASL Level | | | | | | | |
| | ASL I | 43 | 860 | 4,668.17 | 3,225.89 | 0.70 | 0.46 |
| | ASL III | 123 | 2,460 | 5,568.92 | 3,453.67 | 0.74 | 0.44 |
| Neurotype | | | | | | | |
| | Neurotypical | 131 | 2,620 | 5,488.406 | 3,561.857 | 0.74 | 0.44 |
| | Neurodiverse | 35 | 700 | 4,762.54 | 2,743.62 | 0.67 | 0.46 |

TABLE 6 Summary descriptive statistics for non-linguistic PTT by disability category.

| Diagnostic Category | Participants ($n = 166$) | Number items | Mean RT (ms) | SD RT (ms) | Mean proportion correct | SD proportion correct |
|---|---|---|---|---|---|---|
| No diagnosis reported | 131 | 2,620 | 5,488.41 | 3,561.857 | 0.74 | 0.44 |
| Visual | 5 | 100 | 4,712.32 | 2,466.91 | 0.63 | 0.49 |
| ADD/ADHD | 10 | 200 | 4,911.82 | 3,250.93 | 0.73 | 0.44 |
| LD | 5 | 100 | 4,243.35 | 2,795.06 | 0.55 | 0.50 |
| Other* | 9 | 180 | 4,227.76 | 1,978.16 | 0.73 | 0.44 |
| Multiple** | 6 | 120 | 5,784.17 | 2,726.84 | 0.61 | 0.49 |

*Including Dyslexia ($n = 3$), Auditory Processing Disorder ($n = 2$), Language Impairment ($n = 2$), Narcolepsy ($n = 1$), and Concussion ($n = 1$).
**Including LD + ADD ($n = 3$), LD + Auditory Processing Disorder ($n = 1$), LD + Dyslexia ($n = 1$), LD + Visual ($n = 1$).

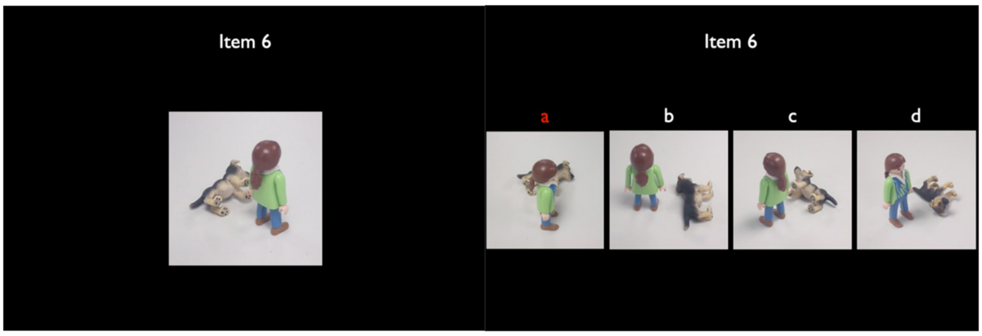


FIGURE 1
Non-linguistic perspective taking task item example.

among the lowest scores in the ASL-DT as well (Figure 1). These observations align with studies of spoken L2 learning showing that "learning disabled" students perform most like their "low-achieving" peers, where other diagnoses such as ADHD might be spared (Sparks et al., 2008). Likewise, our findings also align with research on visuospatial skills in ADHD and dyslexic adults, where Laasonen et al. (2012) finds that the latter group is impaired compared to a control group while the ADHD group is not.

The main effects of sex in the perspective-taking tasks echo, in part, similar findings in previous research that males outperform females on visual-spatial tasks primarily in non-linguistic contexts, and less so in linguistic settings. Notably, Emmorey et al. (1998) finds that the effect of sex is only revealed in the non-linguistic, but not the ASL, versions of visual-spatial tasks. Likewise, Brozdowski et al. (2019) find that for deaf participants in a classifier-based spatial task, there is only a marginal (i.e., not statistically significant) effect of gender, where males outperformed females. Both Hegarty (2017) and Tarampi et al. (2016), by contrast, find robust effects of sex in non-linguistic mental rotation and spatial perspective-taking tasks in hearing groups. Tarampi et al. (2016) demonstrate that males only outperform females in the version of a visual-spatial processing components that is non-*social*. That is, when a figure of a human body was included, females no longer underperformed. They attributed this result, in part, potentially to stereotype threat. In comparison, we found no effect of sex on performance of the ASL-DT. Likewise, there was an effect of sex on response time for the ASL-PTCT, but not the NL-PTT, where males outperformed females. We did find an effect of sex on accuracy in both the ASL-PTCT and NL-PTT, though it may be worth noting this result bordered significance ($p = 0.05$). Because the ASL-PTCT contains live videos of a human, whereas the NL-PTT only contains a figure of a human, social as well as linguistic factors could similarly be affecting the differences between male and female participants. The fact that we did observe a statistically significant difference between male and female participants on the ASL version of the task, despite evidence from previous research with deaf participants that does not find this pattern, may also be due to the hearing status and ASL experience level of our participants. Further research disentangling linguistic from social context, especially in a signed language where the signer's body must be visible, may prove useful in understanding the underlying factors driving performance differences between sexes.

The ASL III students outperformed the ASL I students on the ASL-DT, but not on either of the perspective-taking tasks. It is possible that three semesters of ASL is enough for signed phonological skills to significantly improve, but not visual-spatial skills (linguistic or otherwise). This analysis is supported by the fact that classifiers are late-mastered grammatical components for both first and second language signers (Morgan et al., 2008; Boers-Visker and Van Den Bogaerde, 2019). It is also possible that the sheer difficulty of the ASL-DT task leant to differentiating the two groups; the maximum score was only sixty-three percent, compared to a ceiling with perfect scores on the perspective-taking measures.

What is striking is that the effects of disability were not observed in the ASL version of the perspective-taking task, but were in the non-linguistic version. One possibility is that some component of linguistic context is generally equalizing for between group-discrepancies. In other words, some relatively universal factor is available from language context to support all learners and is enough to compensate for any potential population differences related to visual-spatial computation.

This would account for the fact that our result mirrors the findings on sex in linguistic vs. non-linguistic tasks as mentioned above (Emmorey et al., 1998; Tarampi et al., 2016; Hegarty, 2017; Brozdowski et al., 2019). However, such an analysis is complicated by the fact that both the neurotypical and the collective disability groups, as well as most specific diagnostic groups, had both lower accuracy and longer response times on the ASL-PTCT compared to the NL-PTT. Conversely, this fact also rules out an explanation that the NL-PTT was simply harder than the other tasks. In fact, the ASL-DT task seemed to be the most difficult task by far and did not yield any differences between neurotypical and disability groups.

An alternative interpretation is that some specific aspect of the NL-PTT is problematic for the disabled learners, and in particular, the learning disability group. For example, perhaps the difference between encoding and retrieving static images vs. video stimuli presents an inherent challenge for the disability groups. However, this is yet again complicated by the fact that the self-identified disabled learners overall and the learning disability group specifically both had higher accuracies and shorter response times for the NL-PTT compared to the ASL-PTCT.

Finally, another prominent possibility is that the tasks administered in the present study do not target compromised cognitive abilities in the given disability populations. It is possible that with a different set of tasks (e.g., those explicitly designed to probe working memory and short-term memory), there would be a more prominent distinction between neurotypical and disability groups, as well as in between specific disability categories.

A generous interpretation of the results is that the language-based skills involved in the ASL version of the perspective-taking place reliance on language skills for which the neurotypical and disabled learners have equal access too. Such students might come into the ASL classroom, despite differences in visual-spatial processing skills, approaching with a similar language foundation in terms of learning a signed language (i.e., being M2L2 learners). While the process of learning the new language and modality may be taxing overall, the disabled learners aren't more susceptible to these difficulties compared to the neurotypical group. Crucially, there is no evidence here that the signed modality is specifically disadvantageous to disabled learners. This aligns well with the anecdotal and quantitative reports provided by disabled signers in Singleton and Martinez (2015), who in fact, if anything, indicated a *positive* experience with signed language learning. As mentioned by students with both ADHD and dyslexia in the aforementioned study, learners may simply find the modality more stimulating and engaging due to the method of articulation. Further investigation is warranted to determine, if, for example, the slower signing speed aids those with temporal processing deficits as suggested by Quinto-Pozos (2014). It also may be worth empirically investigating the propensity for signed language stimuli to engage the attention of individuals with attentional challenges, particularly in comparison to non-linguistic visual stimuli.

These results have interesting implications for both M2L2 sign learning generally and that of neurodiverse and/or disabled learners. First, while phonological perception is improved as we expect by experience, classifier perception is not. This may call for more prolonged attention to instruction in this domain beginning early on in ASL coursework, especially receptively. However, it also may reflect an appropriate L2 trajectory that is not yet fully realized within the course of three semesters. Instructors may want to intentionally incorporate receptive practice that varies on perspective shifts and the position of the interlocuter with respect to the perceiver.

Disabled students—particularly, those categorized as having a sort of learning disability—may require additional instruction and support from ASL teachers in comparison to neurotypical peers when it comes to spatial processing. As far as these discrepancies only being significant in the NL-PTT, this could possibly be related to construing sign spatial arrangements from static representations, which might imply difficulty with, for example, photos in textbooks as opposed to videos. While there was no statistically significant difference according to neurotype (disabilty vs. neurodiverse) in the ASL-PTCT, it is worth noting that the performance of the learning disability group is still very poor (having a mean of 0.50 for proportion accuracy, compared to the neurotypical mean proportion accuracy of 0.71), as well as that of the visual impairment group and multiple diagnosis group, to a lesser degree (both having means of 0.63 for proportion accuracy). ASL instructors may want to provide additional, targeted opportunities for receptive practice to individuals with these specific diagnoses, perhaps aided with more explicit strategies for improving spatial reasoning and classifier skills.

There are a number of limitations to this project. First, as noted in the analysis, the categorization of the diagnostic types is far from ideal. These groups were also analyzed as part of an exploratory analysis, as opposed to be collected intentionally. Additionally, pooling all diagnostic types together in one "disability" category for sake of comparison to the "neurotypical" group is limiting. In doing so, we have collapsed a very diverse set of individuals into one group, which we might not expect to be homogeneous (and in fact, the results suggest they are not). Finally, it is worth noting again that the self-identification of diagnoses by the participants does not necessarily theoretically align with how these disabilities are conceptually categorized. For example, individuals identified as being dyslexic without identifying a learning disability, and we chose to follow the indications of participants. Future works should explicitly target specific diagnostic groups (which may be very low incidence as M2L2 signed language learners) and prioritize thorough data collection with a battery of measures. Ideally, these measures would also include validated diagnostic assessments and standardized assessments of skills such as visual and auditory working memory, for example, to create baselines based on language-independent and language dependent cognitive skills across potentially diverse groups.

A second limitation is that neither the ASL-PTCT or the NL-PTT have validation and reliability measures. There was also a high degree of variance for both proportion correct and response time for all groups in both versions of the task. Relatedly, we did not have a validated measure of ASL proficiency for baseline comparison, such as a test of ASL production. Unfortunately, we do not have production data since there was limited time during data collection sessions. And finally, perhaps most importantly in terms of lacking measures, we did not provide a comparison to an active spoken language-based perspective-taking task.

In summary, we have found no evidence, even for diagnostic groups with poor non-linguistic visuospatial processing relative to their peers, that the modality of signed language is inherently disadvantageous to disabled M2L2 learners. It is promising that, despite minimal empirical background concerning disabled learners in M2L2 learning contexts, we find no evidence of a distinct signed language processing gap between neurotypical students and those with the most common categories of disabilities in signed language learning classrooms. While it is important to caution against the unfounded notion that signed languages are inherently less complex or easier to learn compared to spoken languages (Jacobs, 1996), it has been suggested in the past that specific features of the signed signal (signing speed, ease of access to articulators, etc.) could be supportive to individuals with processing impairments (Quinto-Pozos, 2014). There may, in fact, be something supportive about signed language learning to such disabled learners that leads to attenuating and/or masking differences between disabled and non-disabled groups.

Future work, as mentioned above, should move beyond this exploratory analysis in targeting specific disability groups and utilizing batteries of tasks selected to target specific challenges as evidenced by former literature within these groups. Remaining to investigate, as well, is the differentiation between the influence of language context generally compared to the influence of signed language context specifically, which could be probed by including either including groups with minimal or no sign exposure, or performing longitudinal analyses of sign learners.

## Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## Ethics statement

The studies involving human participants were reviewed and approved by International Review Board, University of Texas at Austin. The patients/participants provided their written informed consent to participate in this study. Written informed consent was not obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

## Author contributions

DQ-P designed and oversaw collection of data, which was provided as a source for the presented secondary data analysis conducted by TJ. TJ designed the analysis and authored the manuscript under the advising of JS and DQ-P, both of whom provided direction and feedback in each domain. MD also provided input on the analysis. MD and TJ prepared and coded data for analysis and also wrote and executed the code for the statistical analyses. TJ prepared the manuscript with input from DQ-P and JS. TJ, DQ-P, and JS prepared the revised and approved version for publication. All authors contributed to the article and approved the submitted version.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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## Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fcomm.2022.920752/full#supplementary-material

## References

American Psychiatric Association. (1994). *Diagnostic and Statistical Manual of Mental Disorders, 4th Edn*.

American Psychiatric Association. (2013). *Diagnostic and Statistical Manual of Mental Disorders, 5th Edn*. doi: 10.1176/appi.books.9780890425596

American Speech Language Hearing Association. (2023). *Central Auditory Processing Disorder*. Available online at: https://www.asha.org/practice-portal/clinical-topics/central-auditory-processing-disorder/ (accessed April 2, 2023).

Andrews, E. E., Forber-Pratt, A. J., Mona, L. R., Lund, E. M., Pilarski, C. R., and Balter, R. (2019). SaytheWord: a disability culture commentary on the erasure of "disability." *Rehabil. Psychol.* 64, 111–118. doi: 10.1037/rep0000258

Armstrong, I. T., and Muñoz, D. P. (2003). Attentional blink in adults with attention-deficit hyperactivity disorder: Influence of eye movements. *Exp. Brain Res.* 152, 243–250. doi: 10.1007/s00221-003-1535-0

Arries, J. F. (1999). Learning disabilities and foreign languages: A curriculum approach to the design of inclusive courses. *Mod. Lan. J.* 83, 98–110. doi: 10.1111/0026-7902.00008

Bacon, A. M., Parmentier, F. B. R., and Barr, P. (2013). Visuospatial memory in dyslexia: Evidence for strategic deficits. *Mem. Hove* 21, 189–209. doi: 10.1080/09658211.2012.718789

Bertilsdotter Rosqvist, H., Chown, N., and Stenning, A. (2020). *Neurodiversity Studies: A New Critical Paradigm, Roudledge Advances in Sociology*. Abingdon, New York, NY: Routeledge.

Bochner, J. H., Christie, K., Hauser, P. C., and Searls, J. M. (2011). When is a difference really different? Learners' discrimination of linguistic contrasts in American sign language. *Lang. Learn.* 61, 1302–1327. doi: 10.1111/j.1467-9922.2011.00671.x

Boers-Visker, E., and Van Den Bogaerde, B. (2019). Learning to use space in the L2 acquisition of a signed language: two case studies. *Sign Lang. Stud.* 19, 410–452. doi: 10.1353/sls.2019.0003

Bottema-Beutel, K., Kapp, S. K., Lester, J. N., Sasson, N. J., and Hand, B. N. (2021). Avoiding ableist language: Suggestions for autism researchers. *Autism Adulthood*. 3, 18–29. doi: 10.1089/aut.2020.0014

Brozdowski, C., Secora, K., and Emmorey, K. (2019). Assessing the comprehension of spatial perspectives in ASL classifier constructions. *J. Deaf Stud. Deaf Educ.* 24, 214–222. doi: 10.1093/deafed/enz005

Chamberlain, R., Brunswick, N., Siev, J., and McManus, I. C. (2018). Meta-analytic findings reveal lower means but higher variances in visuospatial ability in dyslexia. *Br. J. Psychol.* 109, 897–916. doi: 10.1111/bjop.12321

Chen Pichler, D., and Koulidobrova, E. (2016). "Acquisition of sign language as a second language," in *The Oxford Handbook of Deaf Studies, Language, and Education, 2nd Edn*, eds M. Marschark and P. E. Spencer (Oxford University Press), 218–230.

Emmorey, K., Klima, E., and Hickok, G. (1998). Mental rotation within linguistic and non-linguistic domains in users of American sign language. *Cognition* 68, 221–246. doi: 10.1016/S0010-0277(98)00054-7

E. M. vs. Pajaro Valley United School District, (9th c. 2014).

Gallego-Martínez, A., García-Sevilla, J., and Fenollar-Cortés, J. (2018). Implication of visuospatial and phonological working memory in the clinical heterogeneity of Attention-Deficit/Hyperactivity Disorder (ADHD). *An. Psicol. Murcia Spain* 34, 16. doi: 10.6018/analesps.34.1.289671

Garcia, R. B., Mammarella, I. C., Tripodi, D., and Cornoldi, C. (2014). Visuospatial working memory for locations, colours, and binding in typically developing children and in children with dyslexia and non-verbal learning disability. *Br. J. Dev. Psychol.* 32, 17–33. doi: 10.1111/bjdp.12019

Gillam, R. B., Montgomery, J. W., Gillam, S. L., and Evans, J. L. (2017). "Working memory in child language disorders," in *Handbook of Child Language Disorders, 2nd Edn*, ed R. G. Schwartz (Routledge), 213–237.

Hegarty, M. (2017). Ability and sex differences in spatial thinking: what does the mental rotation test really measure? *Psychon.* Bull. *Rev.* 25, 1212–1219. doi: 10.3758/s13423-017-1347-z

Ho, A. (2020, July 27). *Supporting Visual-Spatial Processing Needs in a Mathematics Classroom. The Knowledge Network for Innovations in Learning and Teaching (KNILT).* Available online at: https://knilt.arcc.albany.edu/Supporting_Visual-Spatial_Processing_Needs_in_a_Mathematics_Classroom

Individuals with Disabilities Education Act, 20 U.S.C. § 1400. (2004).

Jacobs, R. (1996). "Just how hard is it to learn ASL? The case for ASL as a truly foreign language," in *Multicultural Aspects of Sociolinguistics in Deaf Communities*, ed C. Lucas (Gallaudet University Press), 183–226.

Kałdonek-Crnjaković, A. (2018). *The cognitive effects of AHD on learning an additional language*. Govor. 35, 215–227.

Kormos, J. (2017a). "An overview of specific learning difficulties," in *The Second Language Learning Processes of Students with Specific Learning Difficulties, Second Language Acquisition Research Series*, ed J. Kormos (Routledge), 1–25.

Kormos, J. (2017b). "Assessing the second language skills of students with specific learning difficulties," in *The Second Language Learning Processes of Students with Specific Learning Difficulties, Second Language Acquisition Research Series*, ed J. Kormos (Routledge), 94–110.

Laasonen, M., Salomaa, J., Cousineau, D., Leppämäki, S., Tani, P., Hokkanen, L., et al. (2012). Project DyAdd: Visual attention in adult dyslexia and ADHD. *Brain Cogn.* 80, 311–327. doi: 10.1016/j.bandc.2012.08.002

Learning Disabilities Association of America. (2013a). *Right to an Evaluation of a Child for Special Education Services*. Available online at: https://ldaamerica.org/advocacy/lda-position-papers/right-to-an-evaluation-of-a-child-for-special-education-services/ (accessed February 21, 2023).

Learning Disabilities Association of America. (2013b). *What Are Learning Disabilites?* Available online at: https://ldaamerica.org/advocacy/lda-position-papers/what-are-learning-disabilities/ (accessed February 21, 2023).

Li, C. R., Lin, W., Chang, H., and Hung, Y. (2004). A psychophysical measure of attention deficit in children with attention-deficit/hyperactivity disorder. *J. Abnorm. Psychol.* 113, 228–236. doi: 10.1037/0021-843X.113.2.228

Lin, H.-Y., Hsieh, H.-C., Lee, P., Hong, F.-Y., Chang, W.-D., and Liu, K.-C. (2017). Auditory and visual attention performance in children with ADHD: the attentional deficiency of ADHD is modality specific. *J. Atten. Disord.* 21, 856–864. doi: 10.1177/1087054714542004

Lipowska, M., Czaplewska, E., and Wysocka, A. (2011). Visuospatial deficits of dyslexic children. *Med. Sci. Monit.* 17, CR216–CR221. doi: 10.12659/MSM.881718

Łockiewicz, M., and Bogdanowicz, K. M., Bogdanowicz, M. (2014). Psychological resources of adults with developmental dyslexia. *J. Learn. Disabil.* 47, 543–555. doi: 10.1177/0022219413478663

Looney, D., and Lusin, N. (2019). *Enrollments in Languages Other Than English in United States Institutions of Higher Education, Summer 2016 and Fall 2016: Final Report*. Modern Language Association, (No. 24). Available online at: https://www.mla.org/Resources/Research/Surveys-Reports-and-Other-Documents/Teaching-Enrollments-and-Programs/Enrollments-in-Languages-Other-Than-English-in-United-States-Institutions-of-Higher-Education

Lys, F., May, A., and Ravid, J. (2014). A cross-departmental approach to supporting students with a disability affecting foreign language acquisition. *Prague J. Engl. Stud.* 3, 85–111. doi: 10.2478/pjes-2014-0019

Martinez, D., and Singleton, J. L. (2018). Predicting sign learning in hearing adults: The role of perceptual-motor (and phonological?) processes. *Appl. Psycholinguist.* 9, 905–931. doi: 10.1017/S0142716418000048

Martinez, D., and Singleton, J. L. (2019). Individual differences in lexical learning across two language modalities: Sign learning, word learning, and their relationship in hearing non-signing adults. *Acta Psychol.* 198, 102892. doi: 10.1016/j.actpsy.2019.102892

Maruta, J., Spielman, L. A., Tseretopoulos, I. D., Hezghia, A., and Ghajar, J., (2017). Possible medication-resistant deficits in adult ADHD. *J. Atten. Disord.* 21, 1169–1179. doi: 10.1177/1087054714538659

Morgan, G., Herman, R., Barriere, I., and Woll, B. (2008). The onset and mastery of spatial language in children acquiring British Sign Language. *Cogn. Dev.* 23, 1–19. doi: 10.1016/j.cogdev.2007.09.003

Nilsen, E. S., Mewhort Buist, T. A., Gillis, R., and Fugelsang, J. (2013). Communicative perspective-taking performance of adults with ADHD symptoms. *J. Atten. Disord.* 17, 589–597. doi: 10.1177/1087054711428947

Paling, R. M. (2020). An empirical study to determine whether ADHD disorder affects the process of language learning. *J. Pyschol. Neurosci.* 2, 1–7.

Quinto-Pozos, D. (2011). Teaching American sign language to hearing adult learners. *Ann. Rev. Appl. Linguist.* 31, 137–158. doi: 10.1017/S0267190511000195

Quinto-Pozos, D. (2014). *Multilingual Aspects of Signed Language Communication and Disorder*. Bristol; Blue Ridge Summit: Multilingual Matters. doi: 10.21832/9781783091317

Quinto-Pozos, D., and Hou, L. (2013). *Development of Perspective-Taking Skills by Deaf Signing Children.* Theoretical Issues in Sign Language Research – TISLR 11, London, United Kingdom.

Quinto-Pozos, D., Singleton, J. L., Hauser, P. C., Levine, S. C., Garberoglio, C. L., and Hou, L. (2013). Atypical signed language development: a case study of challenges with visual-spatial processing. *Cogn. Neuropsychol.* 30, 332–359. doi: 10.1080/02643294.2013.863756

Sanford, C., Newman, L., Wagner, M., Cameto, R., Knokey, A. M., and Shaver, D. (2011). *The Post-High School Outcomes of Young Adults with Disabiliites up to 6 Years After High School: Key Findings From the National Longitudinal Transition Study-2 (NLTS2) [(NCSER 2011-3004)]*. SRI International.

Schaywitz, S. E., and Schaywitz, B. A. (2017). "Dyslexia," in *Handbook of Child Language Disorders, 2nd Edn*, ed R. G. Schwartz (Routeledge), 130–148.

Schneider, E., and Crombie, M. (2003). *Dyslexia and Foreign Language Learning.* David Fulton Publishers. doi: 10.4324/9780203458709

Secora, K., and Emmorey, K. (2020). Visual-spatial perspective-taking in spatial scenes and in american sign language. *J. Deaf Stud. Deaf Educ.* 25, 447–456. doi: 10.1093/deafed/enaa006

Sims, G., and Delisi, J. (2019). *An Introductory Guide to Understanding Cognitive Disabilities*. Deque. Available online at: https://www.deque.com/blog/an-introductory-guide-to-understanding-cognitive-disabilities/ (accessed February 21, 2023).

Singer, J. (1998). *Odd People In; The Birth of Community Amongst People on the "Autistic Spectrum"*, (Thesis). University of Technology, Sydney, Australia.

Singleton, J., and Martinez, D. (2015). *ASL Learning Among Hearing Students with Language & Learning Impairments*. Preconference Presentation, Society for Research in Child Development, Philadelphia, PA, United States.

Singleton, J. L., Quinto-Pozos, D., and Martinez, D. (2019). "Typical and atypical sign language learners," in *The Routledge Handbook of Sign Language Pedagogy* (Routledge), 279–292.

Sparks, R. L. (2016). Myths about foreign language learning and learning disabilities. *Foreign Lang. Ann.* 49, 252–270. doi: 10.1111/flan.12196

Sparks, R. L., Humbach, N., and Javorsky, J. (2008). Individual and longitudinal differences among high and low-achieving, LD, and ADHD L2 learners. *Learn. Individ. Differ.* 18, 29–43. doi: 10.1016/j.lindif.2007.07.003

Tarampi, M. R., Heydari, N., and Hegarty, M. (2016). A tale of two types of perspective taking: sex differences in spatial ability. *Psychol. Sci*. 27, 1507–1516. doi: 10.1177/0956797616667459

Valdois, S., Bosse, M.-L., and Tainturier, M.-J. (2004). The cognitive deficits responsible for developmental dyslexia: review of evidence for a selective visual attentional disorder. *Dyslexia Chichester Engl*. 10, 339–363. doi: 10.1002/dys.284

Welles, E. B. (2004). Foreign language enrollments in United States institutions of higher education, fall 2002. *Profession*. 2004, 128–153. doi: 10.1632/074069504X26458

Williams, J. T., Darcy, I., and Newman, S. D. (2017). The beneficial role of L1 Spoken language skills on initial L2 sign language learning: cognitive and linguistic predictors of M2L2 acquisition. *Stud. Second Lang. Acquis*. 39, 833–850. doi: 10.1017/S0272263116000322