frontiers | Frontiers in Language Sciences

TYPE Review
PUBLISHED 27 January 2025
DOI 10.3389/flang.2025.1504770

OPEN ACCESS

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RECEIVED 01 October 2024
ACCEPTED 02 January 2025
PUBLISHED 27 January 2025

CITATION
Martínez-Tomás C, Baciero A, Lázaro M and Hinojosa JA (2025) What do pseudowords tell us about word processing? An overview. *Front. Lang. Sci.* 4:1504770.
doi: 10.3389/flang.2025.1504770

What do pseudowords tell us about word processing? An overview

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This article provides an overview of the use of pseudowords—letter strings that resemble real words by adhering to phonotactic and orthotactic rules (e. g., fambo follows the rules of English phonology and orthography, but it does not have an actual meaning)—in written word processing research, with a focus on readers in alphabetic languages. We review how pseudowords have been used in research to isolate specific features of words to examine the cognitive mechanisms underlying various aspects of their processing, including orthographic, phonological decoding, lexical-semantic, and syntactic components, as well as to the way those empirical observations have shaped theories and models of word recognition. The overview also considers their broader applications, such as in studying non-alphabetic scripts, speech processing, and language disorders like dyslexia. By providing a focused synthesis of empirical findings, this article underscores the critical insights that research using pseudowords offers into the interconnected nature of cognitive mechanisms in language processing.

KEYWORDS

pseudowords, word recognition, orthography, print-to-sound, semantics, syntax

1 Introduction

A large (and growing) body of research in psycholinguistics relies on the use of word-like stimuli to study different mechanisms underlying language processing. These stimuli include pseudowords, which are strings of letters that follow the phono- and orthotactical rules of a given language but, in principle, lack conceptual referents and entries in the mental lexicon in such language. For instance, *besder* is a string of letters that follows the permissible phonological and orthographic rules in English, yet is not a real word. In contrast, strings of letters that do not follow such rules (e.g., pbominj), are not considered pseudowords and are commonly referred to as *illegal non-words*. While processing pseudowords may involve strategic or metalinguistic processes that are not necessarily involved in the processing of real words (Levy, 1987), they have nonetheless provided valuable insights into the different components underlying word processing, including orthographical (Grainger, 2018; Perea et al., 2023a), phonetic and phonological (Sidhu and Pexman, 2018; Seidenberg et al., 1996), semantic (Dorffner and Harris, 1997), morphological (Longtin and Meunier, 2005; Snyder, 1995), or syntactic aspects (Cheon et al., 2020; Dołżycka et al., 2022; Opitz and Friederici, 2004).

The body of research using pseudowords on word recognition processes is extremely large—just a quick search on Google Scholar for research involving "word recognition" and "pseudowords" yields more than 5000 entries in the last 5 years alone. Therefore, any research overview of the topic will necessarily be selective. For this reason, the present paper's goal is to describe how pseudowords have been used to study the cognitive mechanisms that underlie written word recognition within alphabetic languages. Specifically, our aim is to present key behavioral and physiological findings that have been central to the development and refinement of theoretical and computational models of word processing, while also describing the main theoretical approaches that attempt to explain such findings. The structure of the present review will be theoretically grounded on an adaptation of the framework described by Grainger (2024) (see Figure 1; see also Figure 4 in Grainger, 2024), allowing us to organize the description of how pseudowords have been used in the study of written word recognition into four key processing components: orthographic processing, phonological decoding –both part of the processing of the *word-form*—, lexical-semantic integration, and sentence-level syntactic processing—note that these components align with most frameworks of word identification (see Perfetti and Helder, 2022). By adopting this framework, we aim to provide a brief but comprehensive overview of the main empirical findings in the literature, with an emphasis on the utility of pseudowords in advancing our understanding of word recognition processes.

2 Orthographic processing

The use of pseudowords is extensive in the written word recognition area, as they serve as an excellent testing tool to examine key issues in the association of a written word with its correct lexical unit on the mental lexicon (i.e., lexical access in reading). Of note, in alphabetic languages, early word processing involves the activation of not only the target word but also similarly spelled lexical units—orthographic neighbors (e.g., singer-ginger, trial-trail, or plane-pane, e.g., Andrews, 1989; Chambers, 1979; Davis and Taft, 2005; see also Perea, 2015, for a review). The use of pseudowords that differ in orthographic similarity with words has been fundamental for our understanding of how readers process orthographic information to, ultimately, activate the correct lexical unit.

Orthographic processing refers to the encoding of letter identities and their positions within a word. Note that written words are both sensory objects (visual for most scripts but also tactile for braille) whose basic elements in alphabetic scripts are letters, and linguist entities that convey meaning, and the processing of orthographic information is considered to be the bridge between low-level sensory processing and higher-level linguistic processing in word recognition (see Grainger, 2018). It is now well-established that word identification in languages that use an alphabetic script is letter-based (as opposed to word-shape-based; see Grainger, 2008, 2018). That is, when we encounter a written word, we must encode the identity of its constituent letters (allowing us to understand that finger and finger are the same word, but not singer), and their positions (allowing us to differentiate between singer, reigns, or signer) in order to correctly activate its representation in the mental lexicon.

Research on written word recognition using pseudowords has offered valuable insights into how orthographic information is processed, by testing the characteristics of letter strings that make them more word-like by being orthographically similar to words. This research has enabled the development and/or refinement of models that connect empirical data with theoretical accounts.

2.1 Letter identity coding

A historical finding in research on letter processing is that letters embedded in words (e.g., the D in WORD) are identified easier than letters embedded in non-words (e.g., the D in ORWD; Reicher, 1969), a phenomenon known as the "word superiority effect" (WSE). Interestingly, this advantage is even greater when comparing the identification of letters within pseudowords vs. orthographically illegal non-words (e.g., D recognized more accurately in NORD than in ORWD), namely the "pseudoword superiority effect" (e.g., Grainger and Jacobs, 1994; Jacobs and Grainger, 2005 [French]; Ripamonti et al., 2018 [Italian]; see Coch and Mitra, 2010 [English], for neurophysiological evidence). These results have been shown using different tasks, the most frequent one being the Reicher-Wheeler task, in which participants, after seeing a word, have to choose which one of two alternative letters was in a specific position (e.g., after briefly showing the string WORD, asking whether a D or a K was in the 4^{th} position), but also in post cued letter-identification tasks (e.g., asking which letter was in the 4^{th} position without giving any possible choices; see Estes, 1975). Notably, exposure to written language has been shown to modulate the word and pseudoword superiority effects, as skilled adult readers tend to show larger effects than children (e.g., Grainger et al., 2003 [French], Kezilas et al., 2016 [English]). Indeed, the effects increase as children get older (e.g., Coch et al., 2012; Juola et al., 1978, [English]).

Nonetheless, orthographic knowledge is not the sole factor that guides letter identity coding in word recognition; perceptual factors also seem to have a role. In a recent study, Lally and Rastle (2023) found that errors in the Reicher–Wheeler task increase when the foil letter alternative is highly similar to the correct letter compared to when the foil letter is dissimilar to the correct letter. For example, presenting the letter string snow, snum or znsq for word, pseudoword and non-word orthographic structures and asking whether the second position contains an h or an n (similar condition) or a t or an n (dissimilar condition). The authors found the same error pattern for the three types of orthographic structures (i.e., word, pseudowords, and non-words), together with the typical word and pseudoword superiority effects (better performance as strings are more word-like). Indeed, previous studies showed that a target word like objetivo (objective in Spanish) is classified as being a word faster when preceded by a visually similar pseudoword prime (e.g., objetiuo), than when preceded by a visually dissimilar pseudoword prime (e.g., objetieo, e.g., Marcet and Perea, 2017, 2018a,b; see also Gutierrez-Sigut et al., 2019 [Spanish] for ERP evidence). This finding suggests that objetiuo activates the lexical representation of objetivo to a greater extent than objetieo during the early stages of processing.

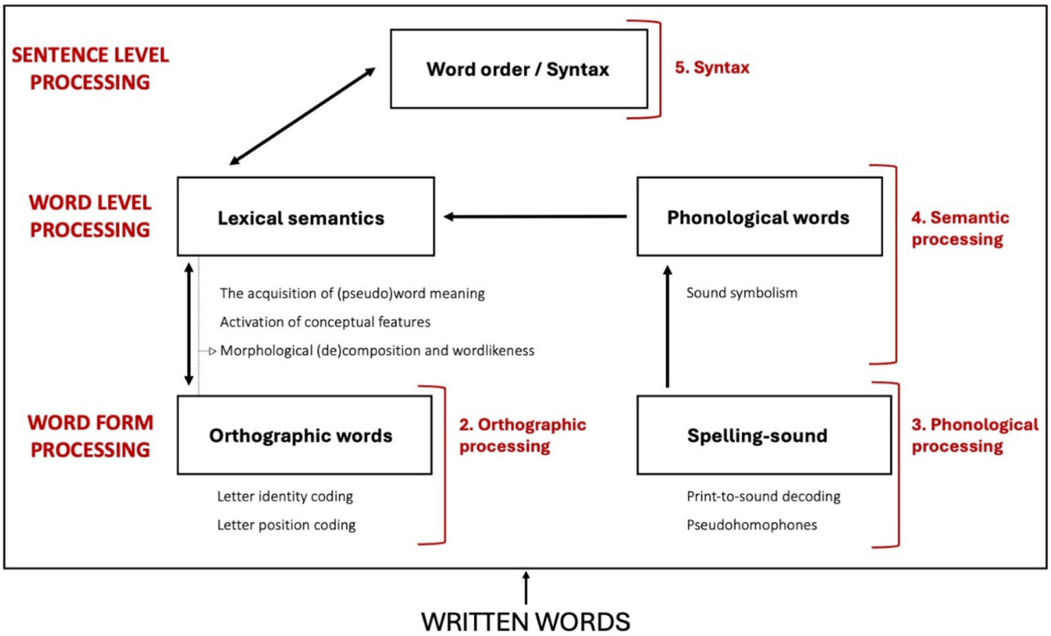

FIGURE 1
A schematic representation of the principal word identification stages discussed in this overview. In bold black, the main processing components involved in progressing from sensory input to meaning during skilled reading in alphabetic languages, based on Grainger (2024). In red, the main sections of the article, linked to their corresponding processing components. In gray, the subsections of the article. Note that this diagram simplifies the cognitive mechanisms underlying the processing of written words, and additional connections among stages are likely present.

Parallel results have been observed in single-presentation lexical decision studies (i.e., *is the string a word?)* when using stimuli frequently presented in the same format, such as logotypes. For example, participants respond more slowly and less accurately to anazon compared to atazon (base word: amazon; e.g., Pathak et al., 2019; Perea et al., 2022a). Likewise, participants also show letter-similarity effects under conditions that limit processing resources, such as brief exposure presentations. For instance, the pseudoword Barcetona is more often misclassified as a word than the pseudoword Barcesona (base word: Barcelona) when presented for only 200 ms (Perea et al., 2023b). Similar effects with common words have also been shown in braille, a writing system that lacks variability across contexts and whose perception of characters is more transient than print (e.g., the tactually similar pseudoword [ausor] is more frequently confused with its baseword [autor; author in Spanish] than the dissimilar pseudoword [aucor]; Baciero et al., 2023), as well as in research involving deaf readers (Gutierrez-Sigut et al., 2022) or individuals with dyslexia (Perea and Panadero, 2014), for whom normal letter-level processing is disturbed (see Conway et al., 2017; Guldenoglu et al., 2014; Lavidor, 2011). Yet, letter-similarity effects vanish with common words in single-presentation lexical decision experiments for neurotypical readers. For instance, anarillo and atarillo (base word: amarillo, yellow in Spanish) yield similar correct response times and accuracy (Perea and Panadero, 2014; Perea et al., 2022b).

The research described above exemplifies the way pseudowords have helped researchers to assess the factors that influence letter identification in multi-letter strings. Overall, current evidence indicates that the context in which a letter is embedded influences its recognition (easier as the context is more orthographically regular). Also, it seems that in some circumstances, particularly those that imply less stimuli variability across contexts and/or that the information collected is more ephemeral, perceptual letter similarity affects the activation of lexical entries. This suggests that letter identity coding within letter strings has some flexibility, and it is affected by both bottom-up and top-down processes, as initially suggested by McClelland and Rumelhart's Interactive-Activation model (McClelland and Rumelhart, 1981; Rumelhart and McClelland, 1982).

Currently, most visual word recognition accounts agree that letter identification within words (or multi-letter strings) is largely based on the mapping of the visual input onto abstract orthographic representations independent of their format (e.g., Coltheart et al., 2001; Davis, 2010; Dehaene et al., 2005; Grainger, 2008; Norris, 2006; see Grainger, 2018 and Grainger and Dufau, 2012 for reviews), explaining why we decode words written in multiple formats (e.g., handwritten, captchas, in different fonts or different cases) without much effort. Moreover, orthographic representations of letter clusters might be generated as print exposure increases, explaining why expert readers are sensitive to orthographic regularities (see Chetail, 2015). Indeed, morphemes—regular patterns of letter clusters and building blocks of meaning—are extracted during the process of word recognition. For instance, priming effects have been shown with morphologically structured stimuli (e.g., word primes: corner–CORN, or pseudoword primes: adorage–ADORE) but not with stimuli with a nonmorphological orthographic relationship (e.g., word primes: brothel–BROTH, or pseudoword primes: adoriln–ADORE) (see McCormick et al., 2009;

Rastle and Davis, 2008). While this issue is described in more detail in the *Semantic Processing* section below (*morphological (de)composition*), these results reinforce the idea that orthographic representations of letter clusters are generated. Nonetheless, it has also been proposed that for orthographic forms that do not have variability in their format (e.g., logotypes), or that are processed under limit resources (e.g., using masked priming paradigm, Forster and Davis, 1984), perceptual traces might remain available in memory (see Labusch et al., 2024). However, no computational model has implemented this idea yet.

2.2 Letter position coding

Most research on orthographic processing has focused on a crucial and robust observation: pseudowords generated by transposing two letters of a word (e.g., jugde—transposing two adjacent letters, or cholocate—transposing two non-adjacent letters) are more frequently confused with their base words (judge or chocolate, respectively) than pseudowords created by replacing those letters (jupte or chotonate) in unprimed lexical decision tasks (e.g., Lupker et al., 2008). Similarly, masked priming studies show a facilitation in the recognition of the target word when preceded by a transposed-letter pseudoword prime, relative to a replaced-letter pseudoword prime (e.g., jugde-JUDGE vs. jupte-JUDGE; Perea and Lupker, 2003; see also Andrews, 1996; Schoonbaert and Grainger, 2004). This effect is known as the transposed-letter effect (see Bruner and O'Dowd, 1958, for the first description of this phenomenon), and it indicates that transposed-letter pseudowords activate the lexical representation of their base words to a greater extent than pseudowords with replaced letters. Hence, suggesting that letter position coding is also a flexible mechanism.

Importantly, research manipulating different characteristics of transposed letter pseudowords has shed light into our understanding of the factors that affect the encoding of a word's letter order. Remarkably, it has been observed that internal letter transpositions generate pseudowords that are more word-like than outer letter transpositions (e.g., first *letter advantage*, where the pseudoword sacino is less confusable with casino than the pseudoword caniso; e.g., Perea et al., 2015 [Spanish]; see Rayner et al., 2006 [English] for eye-tracking evidence; see Scaltritti and Balota, 2013[English] for evidence using a letter identification task, and Grainger et al., 2016 [French] also for developmental evidence). Noticeably, recent work has suggested that both word-initial and word-final positions seem to be more robustly encoded compared to medial positions (e.g., Fischer-Baum et al., 2011), perhaps due to recognizing letter positions in broader spatial configurations (i.e., space-bigrams; Agrawal and Dehaene, 2024). The robustness of transposition effects extends to pseudowords with non-adjacent transpositions (e.g., cholocate more similar to chocolate than chotonate; see Perea and Lupker, 2004 [Spanish]), and the effect persists even in non-canonical presentations, such as when parts of the pseudoword are split across different lines (e.g., cholo- on one line and -cate on another; Perea et al., 2023b; Romero-Ortells et al., 2024 [Spanish]). Moreover, transposed-letter effects have also been reported in preliterate children (Fernández-López et al., 2021) and non-human animals (e.g., baboons, Ziegler et al., 2013, or pigeons Scarf et al., 2016), as well as with pseudowords created from artificial scripts (Fernández-López and Perea, 2023), in *leet* format (e.g., C4TH3DR4L more visually similar to CATHEDRAL than C6TH8DR6L; e.g., Kinoshita et al., 2013 [English], Perea et al., 2008 [Spanish]), or in braille for adjacent transpositions (Baciero et al., 2022 [Spanish]).

Relatedly, pseudowords generated by omitting a letter from an existing word (e.g., mircle or blcn derived from miracle or balcon, respectively), where the letter positions have been altered, also elicit a priming effect compared to unrelated primes (e.g., mircle-MIRACLE vs. nosvlu-MIRACLE; e.g, Lázaro et al., 2018 [Spanish]; Peressotti and Grainger, 1999 [French]). Notably, this priming effect occurs irrespective of whether the omitted letter was repeated within the base word (e.g., "balnce-BALANCE" vs. "balace-BALANCE"; Schoonbaert and Grainger, 2004 [French]). However, the pattern of findings is different for pseudowords created by adding a letter to a word, especially if the letter is repeated. Particularly, pseudowords like silencne [base word: silence] are more often confused with their baseword than pseudowords like silencre in lexical decision studies (Kerr et al., 2021 [French]). Similarly, extra-repeated-letter pseudowords produce larger priming effects than extra-non-repeated-letter pseudowords (e.g., obebuvan-OBEUVAN > obeluvan-OBEUVAN; Trifonova and Adelman, 2022; see also Gomez et al., 2008; Trifonova and Adelman, 2019, [English]).

All these observations are responsible for the development and continual revision of theories and models concerning letter position coding in written word recognition (e.g., Adelman, 2011; Davis, 2010; Dehaene et al., 2005; Gomez et al., 2008; Grainger and Van Heuven, 2004; Norris et al., 2010; Whitney, 2001; see Perea et al., 2023a for a recent review), which can be categorized into two primary approaches. On the one hand, positional uncertainty accounts suggest that there is initial perceptual uncertainty regarding the position of elements (i.e., letters) in space (i.e., word), that it is eventually resolved (e.g., Gomez et al., 2008). On the other hand, orthographic accounts propose that letter order is encoded at a linguistic level of processing, specifically in an intermediate layer of (open) bigram detectors between the letter and word levels (e.g., Grainger and Van Heuven, 2004). Given findings such as those described in the previous paragraphs, a current tendency is to consider that letter position coding might be driven by a hybrid mechanism that includes positional uncertainty, a common characteristic of serial order processing in general, and an orthographic level responsible for representing specifically letter order in strings (e.g., Perea et al., 2023a; Romero-Ortells et al., 2024; see also Adelman, 2011; Grainger and Ziegler, 2011; Snell, 2024 for models that integrate both mechanisms).

3 Phonological decoding

Pseudowords have also been a useful tool to explore the mapping between written forms and their corresponding phonological representations in alphabetic scripts. That is, the way we decode a written word into spoken language, and how these spoken (or phonological) words activate lexical units in our mental lexicon. Research investigating these spelling-to-sound mappings using pseudowords has focused on the sub-lexical grapheme-phoneme conversions, mainly using pseudoword naming tasks and highlighting the role of orthographic depth, particularly print-to-sound consistency (e.g., Coltheart and Leahy, 1992; Marinelli et al., 2020; Ulicheva et al., 2021; Wiley et al., 2024; Zevin and Seidenberg, 2006). Research has also highlighted the role of phonological clues in driving access to the lexical and semantic representations of words, primarily using pseudohomophones (e.g., Grainger et al., 2012; Harm and Seidenberg, 2004; Lukatela and Turvey, 1994a,b).

3.1 Print-to-sound decoding

Pseudowords are particularly valuable for studying how readers process unfamiliar letter combinations, as they allow researchers to isolate grapheme-phoneme correspondence mechanisms without interference from lexical-semantic knowledge. A robust finding across alphabetic orthographies is the *lexicality effect*, where real words are typically read aloud faster and more accurately than pseudowords (e.g., Zevin and Balota, 2000 [English], Pagliuca et al., 2008 [Italian]), presumably due to their more direct lexical access. Relatedly, while naming latencies in general increase as the string length increases for both words and pseudowords, this *length effect* is larger for pseudowords than for words (Weekes, 1997 [English]). This highlights that pseudoword reading relies on sub-lexical processing—fundamental idea of main models of reading aloud. The Dual Route Cascaded (DRC) model (Coltheart, 1978; Coltheart et al., 2001) proposes two routes for uttering printed letter strings: lexical and non-lexical. The lexical route uses word knowledge and relies on a direct access to the phonological lexicon through orthography. The non-lexical route uses the grapheme-phoneme correspondence rules to build up phonological representations. Hence, this model assumes that novel words and pseudowords should use the non-lexical route to be read aloud correctly, whereas irregular or exception words whose pronunciation do not follow those conversion rules should use the lexical route. These assumptions have been questioned by connectionist models. For instance, the "triangle models" (Seidenberg and McClelland, 1989) propose a network of interconnected units of processing (i.e., orthographic, phonological, and semantic), where reading aloud involves using all of them regardless of the letter string at hand (words, pseudowords, or non-words), via the propagation of activation from orthographic input to phonological output using different weights for each unit (see Harm and Seidenberg, 2004, and Seidenberg, 2005, for subsequent developments of the model).

Researchers in this realm have used pseudowords to examine the variables that influence print-to-sound mappings, as well as the types of sub-lexical units that readers employ while reading aloud. One of the main concerns in this line of research has to do with the language, or orthography, of the reader. Specifically, the complexity, consistency and regularity of the spelling-sound correspondences of a given language—concepts closely tied to orthographic depth (see Frost, 1998; see also Schmalz et al., 2015 for a discussion of the terminology). Particularly, behavioral evidence has shown that pseudowords that contain complex multi-letter graphemes (e.g., *fooce* for English readers, where "oo" corresponds to /u:/ and "ce" to /s/) are read aloud slower than pseudowords where every letter is a grapheme (e.g., *fruls*); namely, the *whammy effect* (Rastle and Coltheart, 1998 [English]; see also Rey et al., 1998 [English & French]). Of note, in English, complex multi-letter graphemes often represent inconsistent correspondences. For example, while "oo" is regularly pronounced as /u:/ (e.g., *food*), it can also be pronounced as /ʊ/ (e.g., *book*). Empirical evidence further suggests that readers' pronunciations of pseudowords with inconsistent pattern pronunciations are influenced by existing words with similar patterns: pseudowords with regular neighbors elicit regular pronunciations, whereas those without regular neighbors often lead to irregular pronunciations (Andrews and Scarratt, 1998 [English]). Moreover, performance in pseudoword reading improves when the sub-lexical units in the pseudowords match those of real words (Treiman et al., 1990 [English]). This *body-rhyme effect* is particularly pronounced in orthographies with high inconsistency, such as English. By contrast, in more consistent orthographies like German, reading performance tends to exhibit greater sensitivity to word length (Ziegler et al., 2001 [English & German]; Kwok et al., 2017 [English & Spanish]).

Nonetheless, more consistent orthographies also have complexities. For instance, context-dependent grapheme-phoneme conversion rules (e.g., in Spanish, *g* is pronounced /g/ before *a, o,* or *u* but /x/ before *e* or *i*, as in *abogado* [lawyer] vs. *agente* [agent]; and the same happens with multi-letter graphemes such as *ch*, pronounced /tʃ/, as in *chica* [girl]). Importantly, these context-dependent rules in languages like Spanish (and many others, e.g., French, German, Italian, or Polish) yield consistent and regular pronunciations. Evidence has shown that wordlike pseudowords that contain graphemes associated with complex context-dependent grapheme-phoneme conversion rules (e.g., abogedo [base word: abogado; lawyer]) are more prone to pronunciation errors compared to pseudowords with simpler, context-independent graphemes (e.g., Sebastián-Gallés, 1991 [Spanish]), likely due to lexicalizations (see Perea and Estévez, 2008). Nevertheless, correct pronunciations of pseudowords produce similar latencies regardless of wordlikeness (e.g., deyasuno = degavuno [base word: desayuno; breakfast]; Perea and Estévez, 2008 [Spanish]).

These sub-lexical processing studies in different orthographies have revealed that readers rely on context-insensitive and context-sensitive grapheme-to-phoneme correspondences, as well as correspondences of greater orthographic units (e.g., rhymes, but also perhaps morphemes, Bar-On and Ravid, 2011; Ravid and Schiff, 2006 [Hebrew], Burani and Laudanna, 2003 [Italian]; or syllables, Carreiras and Perea, 2004 [Spanish]) during pseudoword decoding, shedding light on the granularity of phonological representations (see Schmalz et al., 2014). Indeed, developing studies indicate that lexicality effects increase with reading experience in both low- and high-consistency orthographies, although these effects are more pronounced, and reading progress is slower, in languages with low consistent orthographies (Caravolas, 2018 [English, Czech, & Slovak]). Hence, the pronunciation of pseudowords reflects readers' long-term knowledge of print-to-sound correspondences in a given script. Indeed, recent work demonstrates that the variability observed in English pronunciations can be captured through experience-dependent regularity indices, connecting sub-lexical units of varying grain sizes (Wiley et al., 2023).

3.2 The pseudohomophone effect

Most research that aimed to gain knowledge on the activation of phonological information by means of pseudowords relied on the use of pseudohomophones, which are pseudowords that are pronounced like a real word (e.g., brane for brain). Typically, pseudohomophones, compared to other pronounceable pseudowords, elicit faster naming latencies (e.g., Borowsky and Masson, 1999 [English]; Costello et al., 2021 [Spanish]; Peressotti and Colombo, 2012 [Italian]), delayed correct responses in lexical decision tasks (Braun et al., 2015; Ziegler et al., 2001 [German]; Seidenberg et al., 1996 [English]; but see Difalcis et al., 2018 [Spanish]), as well as faster correct responses to target words when preceded by pseudohomophone primes in masked priming lexical decision tasks (e.g., pharm – FARM; e.g., Rastle and Brysbaert, 2006 [English]; Ziegler et al., 2000 [French]). This evidence suggests that the production and identification of pseudohomophones involves accessing the representation of the base words from which they are derived. Moreover, this not only occurs with pseudohomophones but also with pseudowords that are auditory (and orthographically) similar to words (e.g., transposed-phoneme pseudowords such as /baksɛt/ are perceived as being more similar to their base word, /baskɛt/, than control pseudowords such as /bapfɛt/; e.g., Dufour and Grainger, 2022; Dufour et al., 2023). However, while delayed responses in word recognition tasks have been attributed to the conflict generated by the co-activation of phonological information of base words in the absence a corresponding orthographic representation, speeded responses in production tasks rather reflect the ease of computation of articulatory codes in familiar utterances (Seidenberg et al., 1996).

Studies investigating the role of phonological information in guiding lexico-semantic access have reported enhanced pseudohomophone effects in pseudohomophones derived from low-frequency relative to high-frequency base-words in adults (Cuetos and Domínguez, 2002 [Spanish]; McCann et al., 2022; Pexman et al., 2001 [English]; Ziegler et al., 2001 [German]) and beginning readers (Brossette et al., 2024; Grainger et al., 2012 [French]; Tiffin-Richards and Schroeder, 2018 [German]). These base word frequency effects are modulated by manipulations of list-context (e.g., mixed pseudohomophone-non word lists vs pure pseudohomophones lists, or list order effects; see Grainger et al., 2000 [French]; Reynolds and Besner, 2005 [English]), orthographic neighborhood density (Grainger et al., 2000 [French]), or the number of semantic neighbors of their base words (Yates et al., 2003 [English]). Of note, individual differences in phonological skills, such as the ability to discriminate between two sounds of the same category (i.e., categorical perception), influence the access to phonological codes in pseudohomophones whose base word was of high-frequency (Luque et al., 2011 [Spanish]). Finally, evidence from ERP and fMRI studies have shown early base word frequency effects in German around 150 ms in temporo-parietal and fronto-temporal brain regions (Braun et al., 2009, 2015).

Thus, research with pseudohomophones has shown that phonological decoding seems likely to play a role in accessing lexical representations during word production and recognition (see however Cauchi et al., 2020). Current findings also suggest speeded access to lexical representations of pseudohomophones from high-frequency basewords. Importantly, the base word frequency effect has challenged localist models of word recognition like the Dual-Route Cascaded model (Coltheart et al., 2001), or the Multiple Read-Out model (Grainger and Jacobs, 1994). These models claim that lexical access involves inhibitory and cooperative interactions between orthographic and phonological representations using a multiple read-out mechanism. Accordingly, pseudowords that share phonological or orthographic features with words, and those with high baseword frequency elicit more resting activation of the lexical structure, which interferes with classifying the stimulus as a nonword in lexical decisions. Therefore, the finding of faster responses for pseudohomophones whose base word was of high-frequency is at odds with the predictions of these models. Likewise, Parallel distributed models (Harm and Seidenberg, 2004) assume impaired identification of pseudohomophones derived from high-frequency words as a result of a broader level of activation of orthographic, phonological and semantic units in networks that represent word knowledge. More recent versions of these models (e.g., Grainger and Ziegler, 2011), have incorporated a spell-check or verification mechanism to account for the faster access to phonological representation in pseudohomophones with high frequency basewords. During this stage, location-specific orthographic codes are mapped onto phonemes to activate the phonological representation of the baseword. Assuming that knowledge about the spelling of high-frequency basewords has a stronger representation in lexical memories than that of low-frequency basewords, the spell-check is faster for pseudohomophones whose baseword is of high frequency.

4 Semantic processing

Pseudowords are lexical elements intrinsically devoid of meaning. However, there is evidence indicating that individuals exploit systematic statistical regularities between sublexical (e.g., orthographic and phonological cues) and semantic features to make sense of seemingly meaningless linguistic stimuli (Gatti et al., 2024). Therefore, the use of pseudowords has contributed to broadening our understanding about the role of morphological markers in word recognition (Yap et al., 2015). In addition, it has provided insightful clues about the existence of sound symbolic effects in language, which refers to the resemblance between the form, or sound, of a word and its meaning (Dingemanse et al., 2015; Sidhu and Pexman, 2018; Winter and Perlman, 2021). Along this line, several studies have reported associations between sound and meaning, such as size, shape or affective features, in different languages (e.g., Calvillo-Torres et al., 2024 [Spanish]; de Zubicaray et al., 2024; Knoeferle et al., 2017, [English]; Körner and Rummer, 2022 [German]). Finally, research using pseudowords has expanded our knowledge about the acquisition of new concepts and the activation of conceptual features of words (e.g., concreteness or emotion), in both first and second languages.

4.1 Morphological (de)composition and wordlikeness

A relevant question in psycholinguistics concerns the role played by roots or stems and affixes in the lexical representation of morphologically complex words (i.e., words composed of more than one morpheme as in player; e.g., Beyersmann et al., 2020 [French & German]; Bick et al., 2010 [Hebrew]; Carota et al., 2016 [Italian]; Duñabeitia et al., 2008 [Basque]; Gwilliams and Marantz, 2015 [Arabic]; Kazanina et al., 2008, [Russian]; Lázaro et al., 2015 [Spanish]; Prins et al., 2019 [Dutch & Turkish]; Rastle et al., 2004 [English]).

Within this line of research, several studies using pseudowords as stimuli have sought to identify the morphological markers that make a string of letters to look more (or less) similar to actual words (i.e., wordlikeness). Evidence from masked priming and cross-modal priming experiments indicates that suffixed nonword primes speed the visual identification of a stem target (e.g., rapidifier-RAPIDE) whereas non-suffixed primes (e.g., rapiduit-RAPIDE) do not (e.g., Longtin et al., 2003; Longtin and Meunier, 2005 [French]; but see Morris et al., 2011[English]). Subsequent work has refined these findings by showing that this effect is only observed when semantically interpretable pseudowords composed of a stem and a suffix (e.g., rapidifier-RAPIDE)are compared to pseudowords consisting of a non-interpretable combination of stems and suffixes (e.g., garagité-GARAGE; Meunier and Longtin, 2007 [French]), or in low- language proficiency individuals who would rely to a greater extent in morphological segmentation to process complex words (Beyersmann et al., 2015 [French]).

A systematic finding in lexical decision experiments refers to the observation of delayed rejection times (e.g. Burani et al., 1999 [Italian]; Dawson et al., 2018[English]; Lázaro et al., 2022 [Spanish]) and larger peak latencies of pupillary dilations (Lázaro et al., 2023[Spanish]) for pseudowords that include both stems and affixes relative to pseudowords without morphological constituents. Of note, the representation of suffixes is likely to be position-specific, as the morphological interference effect vanishes in pseudowords made up of existing stems and suffixes whose order is transposed (e.g., fulgas [from gasful]; e.g., Crepaldi et al., 2010 [English]). In contrast, stems are coded flexibly and without positional constraints, since transposed-constituent pseudocompounds (e.g., moonhoney [baseword: honeymoon]) are rejected more slowly than control pseudowords (e.g., moonbasin) (Crepaldi et al., 2013 [English]). Finally, morphological interference effects have been reported for children of different ages and in different languages (e.g., Casalis et al., 2015, in 10-year-old French and 9-year-old English children; Lázaro et al., 2024 in 7-, 10- and 12-year-old Spanish children), although there are some differences related to the productivity and transparency of the derivational system of each language (see Casalis et al., 2015).

Current findings from research with pseudowords align with the claims made by theoretical views that argue for the need of an early (i.e., morpho-orthographic) and/or late (i.e., morpho-semantic) morphological decomposition stage in word recognition (e.g., Lelonkiewicz et al., 2023; Marslen-Wilson et al., 2008; Rastle and Davis, 2008; Taft and Nguyen-Hoan, 2010). Specifically, some proposals assume that decomposing pseudowords into its morphemic elements activates semantic cues (e.g., semantic interpretability) which could be potentially integrated into conceptual representations (e.g., the pseudoword quickify would be conceptually related to the meaning of making something quicker; see Feldman et al., 2009). In contrast, evidence from pseudowords is more difficult to reconcile with those distributional models which assume that the access to the morphological structure does not occur before the holistic word representation has been activated, or that morphology emerges as a graded, inter-level representation patterns that reflects correlations among orthography, phonology and semantics (e.g., Seidenberg and Gonnerman, 2000; Giraudo and Grainger, 2001; Stevens and Plaut, 2022; but see, Giraudo, 2005, who suggests that pseudowords activate their stems and affixes through the co-activation of all whole-words to which they are related).

4.2 Sound symbolism

The arbitrariness of linguistic signs was already noted by old Greek philosophers, such as Parmenides, Plato or Aristotle. This concept was inherited in modern linguistics when de Saussure established that a core property of natural language is the capacity of linguistic symbols to combine into limitless conventional forms of the sign. However, this view was quickly challenged when Sapir (1929) observed that participants ascribed bigness to pseudowords containing back vowels (e.g., /a/ as in car), whereas those with front vowels (e.g., /i/, as in sit), tended to be associated with small size (the so-called *mil/mal* effect). Similarly, Köhler (1929, 1947) found that the pseudoword takete tended to be matched with a figure displaying spiky shapes. In contrast, the pseudoword maluma was mainly associated with a curved shape (the so-called *maluma/takete* effect, Köhler, or the *kiki/bouba* effect, Ramachandran and Hubbard, 2001; Westbury, 2005). These findings argue for the coexistence of both arbitrary and non-arbitrary relationships in form-meaning mappings.

Subsequently, a growing number of studies extended these findings by showing a positive association between certain phonemes and/or pseudoword features and several conceptual domains. English participants associate sharp-shaped pseudowords, such as takete or kiki with sourness, and round-shaped pseudowords such as maluma or *bouba* with sweetness (Crisinel et al., 2012; Gallace et al., 2011; Ngo and Spence, 2011). English pseudowords including back vowels (e.g., gugu) are mapped onto bouncing balls displaying slower speeds, and pseudowords with consonant reduplication with vowel alternation (e.g., kiku) are associated with faster bouncing ball speeds (Cuskley, 2013). A relationship has been also observed with motivational states since German and English, pseudowords articulated from the front to the rear (e.g., benoka) and from the rear to the front (e.g., kenoba) are linked to approach and avoidance behavioral tendencies, respectively (Topolinski et al., 2014). German participants generate more pseudowords that include the phoneme /i/ when they are in a positive mood (Rummer et al., 2014), and this phoneme is overrepresented in pseudo-names for pictures depicting smiling persons and positive objects (Rummer and Schweppe, 2019). Finally, in German, complex consonant clusters involving the combination of plosives and sibilants (e.g., speuz) are more likely to occur in pseudowords judged as denoting highly arousing concepts (Schmidtke and Conrad, 2024). Neuroimaging research has shown the neural underpinnings of these effects. In this line, several fMRI studies have shown that the mapping between pseudoword forms and shape depends on the activation of brain areas mediating multisensory integration such as the association auditory cortex or higher-order visual cortices, as well as language-related brain areas such as the left inferior frontal gyrus or the left supramarginal gyrus (e.g., Barany et al., 2023; McCormick et al., 2021; Peiffer-Smadja and Cohen, 2019). Also, evidence from eye-movements indicate that English speakers spend more time fixating both drawings depicting rounded shapes when hearing pseudowords containing phonemes conveying roundedness (as in gubu) and images of pointy shapes when hearing pseudowords with pointy-biased phonemes (as in tite) (Revill et al., 2018).

Within the framework of language acquisition studies, pseudowords have been used to show an early sensitivity to sound symbolism from infancy. In this line, the *bouba/kiki effect* has been observed in 3-year-old English toddlers (Maurer et al., 2006). Also, several studies have reported a facilitative role in learning pseudoverbs designed to be sound-symbolic by matching their sounds with actions depicted in videos (i.e., different manners of walking), in English 3-year-olds (Kantartzis et al., 2011, 2019). Based on these findings, some authors have argued that sound symbolism provides a scaffolding mechanism for language learning in infancy and early-childhood grounded in a biologically endowed ability to map and integrate multi-modal inputs (Imai and Kita, 2014; Spector and Maurer, 2009). However, evidence coming from a meta-analysis on the emergence of sound-meaning associations have challenged this view since spiky sound-shape correspondences in pseudowords emerged at later stages of development compared to round-shape associations (Fort et al., 2018). These findings suggest that basic sensitivity to some sound symbolic cues comes out early in life and facilitates children's mappings of words to their referent, while sensitivity to other types of sound symbolic associations might require greater exposure to linguistic settings (Fort et al., 2018; Tzeng et al., 2017).

Overall, the results of the work summarized here shows a wide variability of systematic cross-modal mappings between perceptual, motor, conceptual, affective, or linguistic aspects of the form of a sign and its (pseudo) referent. These effects have been explained in the light of several theoretical proposals that aimed to interpret sound symbolism effects, like the *frequency code hypothesis* (Ohala, 1984), the *tochastic drift hypothesis* (Levickij, 2013), or the *embodied cognition* approaches (Vainio and Vainio, 2021). Although current evidence is far from being conclusive, these views argue for the existence of different mechanisms that account for these non-arbitrary phenomena, such as the existence of relationships between meaning and phonetic features, body actions or the properties of speech organs, and the existence of statistical-co-occurrences in the environment or in language patterns (see Ekström, 2022; Sidhu and Pexman, 2018; Spence, 2011, for reviews). Just to give a few examples, front vowels are thought to mimic smallness of the referent by reducing the oral cavity when articulating these phonemes while lip rounding resembles the round-edged shape of the picture in the *kiki/bouba* effect (Ramachandran and Hubbard, 2001). Likewise, there is an overlap in facial movements to articulate the phoneme /i/ and those used to smile (i.e., the zygomaticus major) (Garrido and Godinho, 2021).

4.3 The acquisition of (pseudo)word meaning

Evidence from pseudoword learning studies has shed light into the mechanisms underlying the acquisition of word meaning in both monolinguals (James et al., 2023[English]; Rodríguez-Gómez et al., 2018[Spanish]) and bilinguals (e.g., Lu et al., 2017; Zhang et al., 2020; Yang et al., 2023, [Chinese-English]). Within this frame, some studies have explicitly paired pseudowords with definitions (e.g., Bakker et al., 2015 [Dutch]), matched pseudowords with pictorial stimuli (e.g., Bermúdez-Margaretto et al., 2018 [Spanish]), asked participants to generate potential meanings or definitions for pseudowords (e.g., Gatti et al., 2023; Rueckl and Olds, 1993; de Varda et al., 2024 [English]), assigned novel concepts to pseudowords (e.g., James et al., 2023 [English]), or embedded pseudowords in meaningful sentence contexts (e.g., Batterink and Neville, 2011; Borovsky et al., 2010; Frishkoff et al., 2010 [English]; Mestres-Missé et al., 2007; Rodríguez-Gómez et al., 2018 [Spanish]). These behavioral, neuroimaging, eye-tracking, and computational studies, using different tasks such as lexical decision, semantic categorization (i.e., participants decide whether an item belongs to a semantic category), or recall tasks (i.e. participants are asked to remember as many stimuli as possible without the use of any cues) with both children and adults have shown that the new representations (i.e., pseudowords) easily integrate with existing semantic knowledge possibly through associative learning processes. Therefore, once pseudowords have acquired meaning they become novel words. In this sense, compared to pseudowords without learnt meaning, they are processed faster, receive reduced duration eye fixations (Elgort et al., 2024 [English]), and elicit word-like neural activation patterns in a semantic brain network that include frontal, parietal and temporal structures (Bechtold et al., 2019 [German]). Of note, these studies have identified several factors that modulate meaning induction in pseudowords. In this sense, more meaning induction has been reported as the semantic neighborhood density of the novel concept that has been matched with the pseudoword increases (James et al., 2023 [English]). Also, the acquisition of meaning improves in active vs. observational learning and when sensorimotor experience of the object associated with the novel concept is gained through manipulation vs. visual observation (Bechtold et al., 2019 [German]).

All in all, the findings from the literature reviewed in this subsection are in line with the predictions of recent accounts of complementary learning systems models of word learning (e.g., Davis and Gaskell, 2009; Kumaran et al., 2016; McClelland et al., 2020). These models claim that learning systems are *prior-knowledge-dependent*, indicating that new consistent information is integrated rapidly in the context of existing structured knowledge representations. Therefore, similar mechanisms govern meaning acquisition in pseudowords, which are easily matched with prior semantic knowledge.

4.4 Activation of conceptual features

From a different perspective, researchers have also used pseudowords to examine the mechanisms behind the implicit acquisition of meaning in pseudowords (i.e., without providing explicit conceptual cues as in the studies reviewed above). A consistent finding of studies about incidental vocabulary acquisition using lexical decision tasks has been that correct "no" responses to pseudowords that share conceptual features with words are delayed. In this sense, longer response times and lower accuracy have been reported for target pseudowords following semantically related words in a priming paradigm (i.e., sharing higher orthographic elements; Gatti et al., 2023). Similarly, increased orthography-to-semantics consistency (i.e., semantic similarity between pseudowords and their word orthographic neighbors) and high semantic neighborhood (i.e., the number of words that are semantically similar to a pseudoword from prediction-based models) slow reaction times to English pseudowords (see Hendrix and Sun, 2021; Yap et al., 2015). Also, results from eye-tracking studies show decreased total reading times and fixation durations for pseudowords inserted in sentence and text contextually informative frames (Brusnighan and Folk, 2012 [English]; Godfroid et al., 2013 [German-English bilinguals]), or following repeated encounters with a pseudoword embedded in sentences and passages (Joseph et al., 2014 [English]; Pellicer-Sánchez, 2016 [different backgrounds- English bilinguals]). These observations suggest that speakers and readers retrieve conceptual information from semantic memory regardless of the lexicality of the stimulus. In agreement with this view, computational models have successfully induced meaning in pseudowords through the retrieval of basic representational units that map directly onto meaning (e.g., Chuang et al., 2021; Gatti et al., 2024; Ulicheva et al., 2020). Furthermore, these findings suggest that stored statistical regularities in spelling–or orthography–to meaning mappings seem to play a key role in facilitating the activation of meaning-like representations in the absence of explicit semantic or conceptual information.

Another set of studies have investigated interactions between pseudowords and several aspects of the semantic system. Emotion is as a semantic feature of words that involves two core continuous dimensions, valence (i.e., the hedonic tone of a word, from negative or unpleasant, to positive or pleasant) and arousal (i.e., the degree of activation elicited by a word, from calming to exciting) (Bradley and Lang, 1999). These affective properties have shown to influence word processing. Most studies have reported that positive words are recognized faster and acquired earlier in life than neutral words, while evidence for negative words is inconclusive (see Ferré et al., 2024; Haro et al., 2024; Hinojosa et al., 2020; Sabater et al., 2023). Current behavioral and ERP evidence from lexical decision tasks indicates that pseudowords derived from emotionally intense words are categorized more slowly than pseudowords derived from neutral words (e.g., irtus [baseword: ictus] slower than drocedario [baseword: dromedario]; e.g., Sulpizio et al., 2021 [Italian]). This finding suggests that emotion-related pseudowords are more difficult to identify as non-words than neutral words (as summarized in *The acquisition of (pseudo)word meaning* subsection), possibly due to early and rapid activation of the affective features from their base words. Indeed, in a recent study, Gatti et al. (2024) expanded these findings by modeling different sources of valence with the aim of explaining participants' valence judgments for English pseudowords. Their results indicated that sublexical properties (e.g., the letters in the string) accounted for the valence assigned by participants to pseudowords rather than meaning components. This aligns with previous observations of non-arbitrary form-affective meaning mappings in words, as discussed in the *Sound symbolism* subsection.

Also, several studies have focused on the acquisition of emotional meaning through the matching of pseudowords with facial expressions (e.g., Gu et al., 2023, [Spanish]), sentences conveying affective meaning (e.g., Gu et al., 2021 [Spanish]), pleasant and unpleasant odors (e.g., Speed et al., 2021 [Dutch]), or loss- and gain-associations (e.g., Kulke et al., 2019 [German]). Along this line, individuals chose more pseudowords including a disgust sound (e.g., bughas) than neutral (e.g., nadul) to name unpleasant odors like tobacco or dried shrimps (Speed et al., 2021 [Dutch]). Furthermore, using the evaluative conditioning paradigm (which measures changes in the evaluation of a stimulus after co-occurrence with an affective stimulus), it has been shown that individuals give higher valence and arousal ratings to pseudowords that were previously conditioned with words denoting positive and activating concepts (Ando and Kambara, 2023). Also, pseudowords that were associated with negative words (Fritsch and Kuchinke, 2013; Kuchinke and Mueller, 2019 [German]), or sad faces (Gu et al., 2023 [Spanish]) elicited diminished early brain activity, around 150 ms, compared to pseudowords matched with neutral stimuli, which suggests a successful transfer of affective meaning that facilitated pseudoword processing during lexical decisions and silent reading, respectively. Notably, bilingual studies have shown that the acquisition of emotional connotations for pseudowords is faster when they are embedded in emotionally charged paragraphs, compared to neutral ones (e.g., Hao et al., 2021 [Chinese native speakers learning English]).

Another conceptual property that has been investigated using pseudowords is concreteness. It has been repeatedly observed that words with concrete relative to abstract conceptual referents are recognized faster and acquired earlier (i.e., the concreteness effect, e.g., Jessen et al., 2000). This finding has been related to the fact that concrete words have either richer perceptual and verbal representations (according to the dual coding theory, Paivio, 1986), or higher associated contextual information (according to context availability hypothesis, Schwanenflugel et al., 1992) than abstract words. In line with this processing advantage, new meanings for pseudowords embedded in sentence contexts that induce the inference of a concrete conceptual referent are derived earlier that those in sentences contexts that biased toward an interpretation in terms of new abstract meanings even after controlling for context availability (Mestres-Missé et al., 2014, [Spanish]).

The observation that pseudowords mapped to concrete conceptual elements are learned earlier and recognized easier than those associated to abstract concepts has been replicated in both neuroimaging and behavioral studies with a variety of tasks (e.g., lexical decisions, semantic categorization, or recognition) and meaning induction procedures (e.g., providing definitions, embedding pseudowords into sentences, or pairing pseudowords with words; e.g., Palmer et al., 2013, [English];

Mestres-Missé et al., 2009 [Spanish]; see also De Groot and Keijzer, 2000, and Martin and Tokowicz, 2020, for evidence from Dutch-English and English-German bilinguals, respectively). Of note, interaction effects have been reported during the acquisition of emotional and perceptual conceptual features. In particular, pseudowords acquired novel abstract meaning through definitions only when the content was also negative (Guasch and Ferré, 2021[Spanish]). This finding agrees with those embodied theoretical views that have highlighted the role of affective information in the representation of abstract words (e.g., Kousta et al., 2011). All in all, research with pseudowords suggests a different organization in the representation of abstract and concrete conceptual information in semantic networks. In line with this view, a differential involvement of some brain regions in assigning new concrete and abstract meaning to pseudowords words have been reported. Specifically, the association of new concrete (pseudo)words to their meaning relies on the activation of the ventral anterior fusiform gyrus (Mestres-Missé et al., 2009).

5 Syntax

Only a few studies have used pseudowords to investigate syntactic and morphosyntactic processing. This line of research relies on the use of the so-called jabberwocky sentences, in which content words are replaced by pseudowords while retaining morphological markers and function words. Research on this topic has been mainly concerned with preserving different syntactic operations involved in sentence comprehension and production from the influence of other linguistic cues such as semantics, prosody or pragmatics. In this line, Cheon et al. (2020) presented pseudoword sentences to Korean participants in a self-paced reading task (i.e., participants read a sentence word-by-word, hitting a button to get the next word) to show that the semantic and pragmatic features have little influence in the construction of relative clauses and center embedding, two core processes underlying the formation and understanding of complex sentences. Also, in a grammaticality judgment task (i.e., participants are asked to judge whether a sentence is correct or not), Franck and Wagers (2020) used grammatical and ungrammatical (i.e., number mismatch between the head and the attractor nouns) French sentences containing pseudo-nouns and real verbs to examine the structural conditions for attraction errors. Agreement attraction occurs when a target element shows incorrect agreement with a sentence constituent that is not its grammatical controller. The results showed that attraction arose independently of the contribution of semantic constraints. This finding highlights the contribution of morphosyntactic features over semantic similarity in attraction since pseudoword sentences retain morphological markers but are devoid of meaning.

A fruitful line of research comes from several ERP studies that have examined the temporal course in the brain of the interplay between semantics and several levels of syntactic processing using grammaticality judgment tasks with visually presented materials. In a pioneering study, Münte et al. (1997) violated number agreement between German pseudo-verbs and pseudo-nouns. Morphosyntactic mismatches in pseudoword sentences elicited larger amplitudes in a left anterior negativity (LAN) around 300 ms, which indexes the costs associated with the detection of agreement errors between sentence constituents (Molinaro et al., 2011). Using a similar approach, Hahne and Jescheniak (2001) created sentences that included phrase structure errors (i.e., incorrect word class) in German, with pseudo-participles following a preposition. These sentences elicited enhanced amplitudes in an early left anterior negativity (ELAN, around 200 ms) and a late posterior positivity (P600). These components have been related to the processing of word category and parsing operations (e.g., reprocessing and integration), respectively (Hinojosa et al., 2003; Molinaro et al., 2011). Similar findings have been reported with English pseudoword sentences (Yamada and Neville, 2007; see also Rafferty et al., 2024 for recent evidence indicating synchronization of low-frequency neural oscillations in a passive reading paradigm). Of note, these effects display an early development trajectory since they are observed in 36-month-old English children who listened to jabberwocky sentences with word-class anomalies, although pre-schoolers show a delayed latency compared to adults (Silva-Pereyra et al., 2007; but see Usler and Weber-Fox, 2015). Furthermore, evidence from combined fMRI and eye-tracking studies have shown anticipatory eye-movements and increased activation of the inferior frontal gyrus in jabberwocky sentences when making correct syntactic predictions regarding the word category of a target word (Bonhage et al., 2015).

The results of ERP studies with meaningless jabberwocky sentences indicate that early latency parsing operations dealing with syntactic structure building and the computation of agreement relationships are independent of semantic information since ERP waves to incorrect pseudoword sentences resemble those elicited by incorrect word sentences (i.e., ELAN and LAN waves). Regarding late latency processes, the results are controversial. Current data suggest that reanalysis routines initiated to account for disagreement in number features are based on semantics since no P600 effects were found in jabberwocky sentences with morphosyntactic violations. Conversely, the observation of a P600 component to phrase structure errors in pseudoword sentences including word class errors suggests that the parser aims at triggering repair processes even in the absence of semantics.

In sum, an important goal of the literature on the processing of syntax has been to identify the influence of semantic constraints to syntactic parsing operations. Research with pseudowords has shown that some processes such as the construction of relative clauses, the embedment of subordinate clauses within superordinate clauses, or feature-check operations dealing with the early detection of agreement anomalies rely more heavily on syntactic constraints. These results are in agreement with syntactically-driven models of language, which argue that these processes are encapsulated with respect to semantic and pragmatic features (e.g., Franck et al., 2006; Friederici, 2002). In contrast, the parser is more likely to be exposed to conceptual influences while computing reprocessing and integration operations, which aligns with lexicalist approaches to language (e.g., Vigliocco and Hartsuiker, 2002; Vosse and Kempen, 2000) such as the Continued Combinatory Analysis (Kuperberg, 2007) or the Retrieval-Integration model (Brouwer et al., 2017).

6 Conclusions

In this overview we have shown how pseudowords have been extensively used to expand of understandings of several aspects involved in word processing (e.g., Grainger, 2024), such as letter identity and position coding, print-to sound decoding, sound symbolism, morphological composition or the acquisition of meaning. The use of pseudowords seems to be more prevalent in research on orthographic and phonological processing than in research on semantic and syntactic processing, as they serve as valuable tools for investigating the process of lexical access. This disparity has been underscored in the present paper. Moreover, the boundaries between these different domains of processing are often blurred. This highlights the complexity of language processing, suggesting that while distinct cognitive mechanisms are engaged in orthographic, phonological, semantic, and syntactic tasks, they are not entirely independent and may influence one another at different processing stages (see Carreiras et al., 2014). Another important aspect highlighted by this review is the crucial role of regularities in word processing, which seem to facilitate access not only to lexical representations but also to phonological representations and meaning, hence contributing to general processing of linguistic stimuli (see Chetail, 2017; Gatti et al., 2024). Future research with pseudowords should aim not only to further examine the different word processing domains to provide a more nuanced understanding of the cognitive mechanisms involved in them, but also explore the way these systems interact during language processing.

Pseudowords have been particularly important to test the predictions of several accounts that have tried to unravel the mechanisms underlying different stages of word identification. Along this line, within the orthographic processing domain, current evidence seems to favor views of letter position coding that consider mechanisms dealing with both positional uncertainty and the representation of specific letter order (Snell, 2024). Also, research with pseudowords suggest that the acquisition of meaning relies on a mechanism that links new lexical entries with stored knowledge representations (McClelland et al., 2020). In contrast, although findings from studies with a focus on phonological decoding are mainly compatible with those views which have claimed that reading stimuli lacking lexical entries is grounded in grapheme-phoneme correspondence rules to build up phonological representations (Coltheart et al., 2001), data from connectionist approaches argue that reading language stimuli with and without lexical representations involves a common mechanism (Harm and Seidenberg, 2004).

Of note, the relevance of research using pseudowords involves areas beyond the scope of this overview such as pseudoword spelling, studies of word processing in non-alphabetic languages, or in special populations as those with reading impairments, among others. For instance, work investigating the relationship between spelling and sound outside the visual domain is examining questions such as the direction of the flow of activation between orthography and phonology (i.e., feedback and forward consistency, Stone et al., 1997). By developing tools for measuring spelling-sound consistency (i.e., words which pronunciation matches that of similarly spelled words, like face matches the pronunciation of lace or pace; Chee et al., 2020), these studies have shown that the phonographeme and onset/rime levels make a differential contribution to pseudoword spelling, or that consistency has little impact in the reading direction. Moreover, these effects seem to be modulated by individual differences since participants with better lexical skills used more consistent mapping to spell pseudowords (Wiley et al., 2023).

Additionally, the results from studies with non-alphabetic written systems have provided insightful cues in some of the main questions addressed in this overview. Japanese studies with kanji characters have been fruitful in exploring sound symbolism. In this line, Japanese pseudowords containing back vowels (e.g., kotupu) tend to be associated with pictures depicting big animals or dominant behavior, and pseudowords with front vowels (e.g., kitepi) tend to be related with pictures depicting small animals and submissive behavior (Auracher, 2017). Also, some studies have revealed a learning advantage for Japanese pseudowords including sound symbolic clues (e.g., Imai et al., 2008). For instance, Asano et al. (2015), showed increased N400 effects (i.e., a component that indexes impaired semantic integration, Kutas and Federmeier, 2011) in Japanese 1-year-old infants when a visual stimulus (e.g., a rounded shape) mismatched sound-shape associations (e.g., kipi vs. the matched condition moma). Research with Chinese pseudohomophones has shown that base frequency effects are influenced by the frequency of the shared morphemes between pseudohomophones and their base words (Zhou et al., 2010 [Chinese]), or that pseudowords acquire novel abstract concepts through emotionally positive definitions (Jin et al., 2023). Recently, Huang et al. (2021) used pseudowords with and without a homophonic repairing clue (which guided the participants to correct information for comprehending sentences) embedded in meaningful Chinese sentence contexts while participants judged sentence acceptability. Homophonic pseudowords elicited enhanced P600 amplitudes relative to pseudowords, indicating that the reanalysis of sentence structure relies on the integration of both syntactic and non-syntactic features.

Finally, research with pseudowords might be useful to shed light into the mechanisms underlying language impairments, such as dyslexia. For instance, there is behavioral and eye movements evidence from dyslexic children and adults which indicates that they are impaired at identifying letter identity and coding letter position (Kirkby et al., 2022; Perea and Panadero, 2014; Reilhac et al., 2012), or show hinder orthographic representations and weak links between graphemes and phonemes (Luke et al., 2023). On the other side, data from individuals with language impairments are useful to test the predictions of certain models. In this sense, individuals with surface dyslexia are able to perform lexical decision tasks with pseudohomophones but are impaired at reading irregular words, while some individuals with no dyslexia show the opposite pattern, in agreement with the predictions of the DRC model of reading (Boukadi et al., 2016). Additionally, pseudowords has also been used in clinical interventions in individuals with language disorders. For instance, pseudowords have allowed to develop morphological strategies to compensate for phonological difficulties in children (Suárez-Coalla and Cuetos, 2013), or to improve orthographic skills (i.e., phoneme-grapheme conversion system) in the treatment of dysgraphia (Shea et al., 2022).

In sum, in this article we have reviewed how the use of pseudowords has helped researchers to advance the understanding of various aspects of word recognition. Within each domain, we have described relevant empirical findings, briefly discussed their theoretical interpretations, and highlighted their contribution to the refinement of theoretical and computational models of language processing. Naturally, the body of research utilizing pseudowords is extensive and diverse; therefore, we have only provided an overview of a small portion. Nonetheless, we hope we have demonstrated that pseudowords have significantly contributed to the field of word processing, and hold promise for future advancements.

Author contributions

CM-T: Writing – original draft, Writing – review & editing. AB: Writing – original draft, Writing – review & editing. ML: Writing – original draft, Writing – review & editing. JH: Conceptualization, Funding acquisition, Project administration, Supervision, Writing – original draft, Writing – review & editing.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. This work was supported by the Valencian Government under CIGE2023/20 (Ana Baciero) and by Horizon Europe Framework Programme (HORIZON-MSCA-2023-SE-01. Ref. 101182959).

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.

The author(s) declared that they were an editorial board member of Frontiers, at the time of submission. This had no impact on the peer review process and the final decision.

Generative AI statement

The author(s) declare that no Gen AI was used in the creation of this manuscript.

Publisher's note

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