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Fine motor skills predict expressive, but not receptive, language abilities in minimally verbal autistic adults

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Introduction: Previous research suggests that the motor system plays an important role in spoken language development for children and adolescents with autism spectrum disorder (ASD). However, no studies to date have examined this association in minimally verbal autistic adults (mvASD) who have limited to no functional use of spoken language.
Methods: The current study investigated the association between fine motor skills and language abilities in a sample of 34 mvASD and 29 neurotypical (NT) adults 18 to 34 years old. More specifically, we examined whether fine motor skills were differentially related to expressive vs. receptive language abilities, and explored whether the identified motor-language associations remained significant when accounting for nonverbal cognitive skills. Fine motor skills were measured using the Grooved Pegboard Test (GPT) and the Beery-Buktenica Developmental Test of Visual Motor Integration, 6th Edition (VMI-6), expressive and receptive language abilities were measured using the Expressive Vocabulary Test, 3rd Edition (EVT-3) and the Peabody Picture Vocabulary Test, 5th Edition (PPVT-5), and nonverbal cognitive skills were measured using the nonverbal subtest of the abbreviated battery of the Stanford-Binet Intelligence Scales (SB-5 Nonverbal).
Results: Correlation analyses showed that in the mvASD group, fine motor skills were significantly associated with expressive, but not receptive, language abilities. Nonverbal cognitive skills were significantly associated with expressive language abilities and fine motor skills. When all variables were included in a single model, fine motor skills measured by the VMI-6 emerged as the best statistical predictor of expressive language abilities, while nonverbal cognition was the best predictor of receptive language abilities in the mvASD group.
Discussion: Findings suggest for mvASD adults, the motor system is involved in expressive language, while broader cognitive systems play a more important role in receptive language. No significant associations were found in the NT group, indicating that the motor-language association commonly found in NT children may decouple in adulthood. Further research is needed to determine whether current findings can be replicated in a larger sample of mvASD adults using longitudinal data.

KEYWORDS

autism, minimally verbal, language, fine motor, adults

Introduction

Although no longer considered part of the diagnostic criteria, language impairments, including delayed or limited use of spoken language, reduced language comprehension, and challenges with articulation or pronunciation, are common in autism spectrum disorder (ASD; American Psychiatric Association, 2022). Recent estimates suggest that 23.6–63.4% of autistic individuals are diagnosed with a co-occurring language or speech disorder (Casseus et al., 2023; Levy et al., 2010; Rubenstein et al., 2018). Early challenges with language can have long-term and negative impacts on various domains of functioning, including mental health, independent living, employment, social communication, social relationships, and behaviors of concern (e.g., self-injurious and aggressive behaviors; Chan et al., 2023; Howlin et al., 2013; Kirby et al., 2016; Magiati et al., 2014). It is crucial to identify the factors contributing to language impairments in ASD in order to develop targeted interventions that support language and communication abilities that ultimately improve quality of life for autistic individuals and their families.

Minimally verbal individuals with ASD (mvASD) make up around 30% of the autistic population, and are among the most severely impacted by language impairments (Schaeffer et al., 2023; also see Howlin et al., 2014; Kasari et al., 2013; Norrelgen et al., 2015; Pickles et al., 2014). While the definition of "minimally verbal" has varied in the literature, most researchers agree that mvASD includes those with limited functional use of spoken language that can range from no spoken words to the use of a few words or fixed phrases (Bal et al., 2016; Chenausky et al., 2023; Koegel et al., 2020). Unfortunately, this subgroup of ASD has been historically excluded from research (Kasari et al., 2013; Stedman et al., 2019; Thurm et al., 2022), which has stymied our understanding of which factors contribute to language abilities in this population. While the inclusion of mvASD children and adolescents in research has improved over the past decade, only a handful of studies to date have focused on mvASD adults over 18 years of age. Thus, little is currently known about how the language and communication abilities of mvASD individuals may change during adulthood.

Recent work has emphasized that motor skills play an important role in language development for individuals with and without ASD (see Gonzalez et al., 2019 and Hwang and Lee, 2024 for review). For example, a 2024 meta-analysis reported that early motor skills predict both expressive and receptive language abilities in autistic children (Hwang and Lee, 2024). While the precise mechanisms underlying this motor-language association remain up for debate, some researchers have argued that stronger motor skills provide children with more opportunities to interact with objects and people in their environment, which supports their language learning (Iverson, 2010). Others attest that this association is driven by the overlap in neural circuitry involved in the perception and production of spoken language, motor planning, and action (Willems and Hagoort, 2007). A number of brain regions are activated during language comprehension and production, including regions within the language network that are selective to linguistic inputs, as well as primary sensory and motor areas, and areas involved in perception and motor planning that are responsive to both linguistic and non-linguistic inputs (Fedorenko et al., 2024). Studies have shown that fine motor skills in particular, which include movements or actions made with the hands and fingers such as object manipulation, gesturing, and drawing, are positively associated with expressive and receptive language abilities in children and adolescents with ASD (Bhat, 2023; Bhat et al., 2022; Gernsbacher et al., 2008; Luyster et al., 2008; Mody et al., 2017; Simarro Gonzalez et al., 2024; Wu et al., 2021). Fine motor skills measured during infancy have also been shown to predict expressive language outcomes later in development (Bal et al., 2020; Choi et al., 2018; Hellendoorn et al., 2015; LeBarton and Iverson, 2013; LeBarton and Landa, 2019; Li et al., 2023; Wang et al., 2014a). These positive associations between fine motor skills and language abilities remain significant, even after accounting for children's nonverbal cognitive skills (Bhat, 2023; Choi et al., 2018; LeBarton and Iverson, 2013; Mody et al., 2017), which suggests that language impairments in ASD are not solely the result of broader cognitive challenges or co-occurring intellectual disability.

Fewer studies have investigated the association between fine motor skills and language abilities in mvASD samples, despite the high prevalence of both language and motor impairments in this population (Bhat, 2021). One study found that fine motor skills were positively associated with expressive language abilities, as measured by speech intelligibility and mean length of utterances produced by mvASD children during a natural language sample (Butler and Tager-Flusberg, 2023). Another study of mvASD children and adolescents reported that fine motor imitation skills were the best statistical predictor of the number of different words in one's expressive vocabulary (Pecukonis et al., 2019). While less is known about receptive language abilities in mvASD, a recent large-scale study found that motor skills were positively associated with receptive language abilities, as measured by caregiver-report, in mvASD children and adolescents (although note that this study did not separate fine motor skills from gross motor skills in their analyses; Chen et al., 2024).

Despite the importance of this existing work, no studies to date have examined the association between fine motor skills and language abilities in a sample of mvASD adults over 18 years of age. It's important to study motor-language associations in autistic adults, as previous longitudinal studies have found developmental changes in both motor skills and language abilities during adulthood (Howlin et al., 2014; Travers et al., 2017). Thus, we cannot assume that the positive association between fine motor skills and language abilities that has been previously documented in autistic children and adolescents is also present in autistic adults. Further characterizing the association between fine motor skills and language abilities in mvASD adults will not only provide further insight into one possible factor contributing to language impairments in this population, but will also inform the design of interventions that may help to support language outcomes in adulthood.

The aim of the current study was to investigate the association between fine motor skills and language abilities in a sample of mvASD and neurotypical (NT) adults. We were particularly interested in determining whether fine motor skills were differentially related to expressive vs. receptive language abilities, and exploring whether motor-language associations remained significant when accounting for broader nonverbal cognitive skills. Investigating both expressive and receptive language was motivated by the fact that most mvASD individuals have discrepancies between their expressive and receptive language abilities (e.g., higher receptive than expressive; Chen et al., 2024), and therefore, it is possible that different factors may be related to receptive and expressive language skills in this population. Based on previous studies of autistic children and adolescents, we hypothesized that fine motor skills would be positively associated with both expressive and receptive language abilities in our group of mvASD adults (Bhat, 2023; Bhat et al., 2022; Butler and Tager-Flusberg, 2023; Chen et al., 2024; Gernsbacher et al., 2008; Luyster et al., 2008; Mody et al., 2017; Pecukonis et al., 2019; Simarro Gonzalez et al., 2024; Wu et al., 2021), and that these associations would remain significant even after accounting for nonverbal cognitive skills (Bhat, 2023; Choi et al., 2018; LeBarton and Iverson, 2013; Mody et al., 2017). While current research on the association between fine motor skills and language abilities in NT adults is limited, we did not expect to observe a significant association between fine motor and language measures in our NT group (Simarro Gonzalez et al., 2024).

Methods

Participants

Thirty-six mvASD and 30 NT adults 18–40 years old were enrolled as part of a larger study that aimed to characterize the communication abilities of mvASD adults. Participants were recruited from a variety of sources, including the Lurie Center for Autism's recruitment database, clinician referrals, local outpatient clinics, primary care practices, autism societies, school and day programs, online advertisements, social media posts, and flyering within the local community.

All participants had normal, or corrected to normal vision, no reported history of hearing problems, and English as the primary language used at home based on caregiver-report for participants in the mvASD group and self-report for participants in the NT group. The presence of a comorbid psychiatric disorder that was the primary focus of treatment (e.g., schizophrenia, bipolar disorder, severe major depressive disorder, severe anxiety disorder, substance use disorder), a known genetic disorder associated with ASD (e.g., Fragile X Syndrome, Tuberous Sclerosis), neurological problems (e.g., cerebral palsy, lifelong encephalopathy, *in utero* stroke, severe anoxia at birth, meningitis), voice pathologies (e.g., polyp or node on vocal folds), and any other disorders that would make participation in the study unsafe (e.g., unstable seizure disorder, significant cardiac, hepatic, pulmonary, or renal disease) were exclusionary.

ASD diagnosis in mvASD participants was confirmed by a clinical psychologist using the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (DSM-5; American Psychiatric Association, 2022) symptom checklist and the Social Communication Questionnaire (SCQ; Rutter et al., 2003). Eligible mvASD participants had moderate-to-significant speech impairment based on the Clinical Global Impression-Severity (CGI-S) scale, and expressive language skills that fell at or below the 1st percentile according to scores on the Expressive Vocabulary Test (EVT-3; Williams, 2018). Two mvASD participants were excluded because their scores on the EVT-3 were above the 1st percentile. The final sample included 34 mvASD participants (12 female, 22 male).

NT participants did not meet criteria for ASD based on the clinician rated DSM-5 symptom checklist, and did not have a family history of ASD in any first-degree family members. One NT participant was excluded because of a current psychiatric disorder that required treatment with medication. The final sample included 29 NT participants (15 female, 14 male). Demographics for the final sample are presented in Table 1.

Procedure

Written informed consent was obtained from all NT participants. For mvASD participants, written informed consent was provided by a legal guardian or other authorized representative (e.g., health care proxy, close family member) on behalf of each participant prior to enrollment in the study. Verbal and/or written assent was also obtained from mvASD participants if they were able to comprehend the consent form or a simplified assent information sheet and understand at a basic level the risks and benefits involved in the study. Participation involved at least one visit to the Lurie Center for Autism, during which participants completed a battery of standardized assessments including measures of fine motor skills, nonverbal cognitive skills, and expressive and receptive language abilities (described below). All assessments were administered by a licensed clinical psychologist, post-doctoral researcher, or trained research coordinator. NT participants and caregivers of mvASD participants also completed a demographics questionnaire. All procedures were approved by the Massachusetts General Brigham Institutional Review Board (protocol: P000526).

Measures

Fine motor skills

Grooved Pegboard Test (GPT)

The GPT measures fine motor skills, specifically the dexterity and visuomotor coordination of the hands and fingers (Mathews and Klove, 1964). During this task, participants use one hand to place a set of pegs into a series of small holes on a pegboard as quickly as possible. Because the pegs are grooved on one side, participants must rotate and align each peg with the shape of each hole before it can be inserted. The test is first conducted with the dominant hand, and then repeated with the non-dominant hand. In the current study, a maximum time of 180 s for each hand was allowed before the test was discontinued to minimize participant frustration. The amount of time that it took participants to complete the task using their dominant hand was used in analyses.

Beery-Buktenica Developmental Test of Visual Motor Integration, Sixth Edition (VMI-6)

The VMI-6 captures one's ability to integrate visual information with the fine motor action of drawing (Beery et al., 2010). The VMI-6 requires participants to copy a series of geometric shapes of increasing complexity as accurately as possible.

TABLE 1 Sample sociodemographics by group.

	mvASD ($n = 34$)	NT ($n = 29$)
Age (years)	*M* (*SD*): 25.6 (5.0)	*M* (*SD*): 24.4 (3.9)
	Range: 18–34	*Range*: 19–33
Sex		
Female	12 (35.3%)	15 (51.7%)
Male	22 (64.7%)	14 (48.3%)
Race		
Alaskan or Pacific Islander	0 (0%)	0 (0%)
Asian	2 (5.9%)	11 (37.9%)
Caucasian/White	28 (82.4%)	18 (62.1%)
Black	0 (0%)	0 (0%)
More than one race	3 (8.8%)	0 (0%)
Unknown/Not reported	1 (2.9%)	0 (0%)
Ethnicity		
Hispanic or Latino	0 (0%)	1 (3.4%)
Non-Hispanic or Non-Latino	29 (85.3%)	27 (93.1%)
Unknown/Not reported	5 (14.7%)	1 (3.4%)
Highest education level completed		
No schooling completed	7 (20.6%)	0 (0%)
Nursery school to 8th grade	2 (5.9%)	0 (0%)
Some high school, no diploma	12 (35.3%)	0 (0%)
High school graduate, diploma, or equivalent (e.g., GED)	4 (11.8%)	2 (6.9%)
Some college credit, No degree	2 (5.9%)	4 (13.8%)
Trade School, technical school, or vocational training	1 (2.9%)	0 (0%)
Associate's degree	0 (0%)	0 (0%)
Bachelor's degree	0 (0%)	17 (58.6%)
Master's degree	0 (0%)	3 (10.3%)
Professional doctorate	0 (0%)	3 (10.3%)
Other	3 (8.8%)	0 (0%)
Unknown/Not reported	3 (8.8%)	0 (0%)

Values in the table reflect mean (M), standard deviation (SD), and range, or frequencies and percentages. mvASD, minimally verbal autism spectrum disorder; NT, neurotypical.

Nonverbal cognitive skills

Stanford-Binet Intelligence Scales, Fifth Edition (SB-5)—Abbreviated Battery

The SB-5 measures cognition across five dimensions (fluid reasoning, knowledge, visuospatial reasoning, quantitative reasoning, and working memory; Roid, 2003). During the study participants were administered the abbreviated battery, which includes just two subtests (nonverbal fluid reasoning and verbal knowledge), and provides an estimate of intelligence (ABIQ). During the nonverbal subtest of the abbreviated battery, participants identify visual patterns and select the object or picture that best fits within each pattern; this subtest assesses fluid reasoning skills, or the ability to solve novel problems. The verbal subtest assesses verbal knowledge skills and requires participants to identify objects or body parts, label pictures, and describe words. While the verbal subtest was administered to determine ABIQ, only nonverbal subtest scores were used in analyses as all mvASD participants were at floor on the verbal subtest.

Language abilities

Expressive Vocabulary Test, Third Edition (EVT-3)

The EVT-3 is used to evaluate expressive vocabulary skills, defined as the ability to produce spoken language to describe objects, actions, or concepts (Williams, 2018). This assessment requires participants to listen to questions or prompts spoken by the examiner, and then respond to each question or prompt using spoken language.

Peabody Picture Vocabulary Test, Fifth Edition (PPVT-5)

The PPVT-5 measures receptive vocabulary, or the ability to understand the meaning of spoken words (Dunn, 2018). During the PPVT-5, participants listen to single words spoken by the examiner, and then match each word with its appropriate picture in a set of four different pictures.

Analytic plan

Analyses were conducted in SPSS (version 29.0.2) and MPlus (version 8.5; Muthén and Muthén, 1998–2017) using raw scores for all measures, given that standard scores for most mvASD participants were at floor. We first conducted within-group correlation analyses to examine the associations among scores on each measure. Spearman's correlations were used to account for non-normally distributed data, and Bonferroni correction was used to account for multiple comparisons (5 measures × 2 groups) with an adjusted alpha level of $p = 0.005$. Next, we constructed fully saturated structural equation models (SEM) for each group to examine the bivariate associations between scores on each measure while statistically controlling for scores on all other measures and possible confounding covariates (age and sex) within a single model. Robust maximum likelihood estimation was used to account for non-normally distributed data (Finney and DiStefano, 2006). Each group's model included direct paths between measures of fine motor skills and language abilities, and between measures of nonverbal cognitive skills and language abilities. Measures of fine motor skills (GPT and VMI-6) and nonverbal cognitive skills (SB-5 Nonverbal), as well as measures of language abilities (EVT-3 and PPVT-5), were allowed to covary with each other. Participant age and sex (0 = female, 1 = male) were included as covariates in both models, as previous research has shown that language abilities and motor skills in ASD can vary based on age and sex (Howlin et al., 2014; Saure et al., 2023; Travers et al., 2017).

Results

Standardized assessment performance

Raw and standardized scores for each assessment by group are presented in Table 2. The majority of NT participants scored within the average range on each assessment. Participants in

TABLE 2 Standardized assessment performance by group.

	mvASD		NT	
	M (SD)	*Range*	*M (SD)*	*Range*
GPT				
Raw score (seconds)	143.12 (40.89)	59–180	64.90 (11.44)	48–93
Standard score	50.09 (13.49)	45–106	93.38 (19.64)	56–124
VMI-6				
Raw score	13.65 (5.64)	3–26	27.66 (2.09)	21–30
Standard score	49.18 (10.36)	45–87	95.52 (11.25)	57–107
SB-5 ABIQ				
Standard score	50.65 (7.84)	47–76	108.79 (12.32)	88–139
SB-5 nonverbal				
Raw score	14.24 (6.46)	4–29	28.66 (2.44)	24–34
Scaled score	2.29 (2.74)	1–11	10.59 (2.10)	6–15
SB-5 verbal				
Raw score	13.09 (5.52)	3–24	48.14 (6.43)	40–60
Scaled score	1 (0)	1–1	12.34 (2.89)	8–18
PPVT-5				
Raw score	125.30 (22.73)	64–157	220.26 (9.78)	193–234
Standard score	48.63 (7.01)	40–62	108.59 (12.68)	80–130
EVT-3				
Raw score	59.65 (34.13)	0–101	168.30 (10.68)	142–186
Standard score	50.00 (8.29)	40–64	109.41 (10.47)	84–131

Values in the table reflect mean (M), standard deviation (SD) and range of raw and standardized (scaled/standard) scores in participants with minimally verbal Autism Spectrum Disorder (mvASD) and those who are neurotypical (NT). Standard scores between 85 and 115, and scaled scores between 8 and 12 are within the average range. 5 participants are missing the EVT-3 (3 mvASD, 2 NT) and 9 participants are missing the PPVT-5 (7 mvASD, 2 NT). ABIQ, abbreviated battery intelligence quotient; EVT-3, Expressive Vocabulary Test, Third Edition; GPT, Grooved Pegboard Test; NT, neurotypical; PPVT-5, Peabody Picture Vocabulary Test, Fifth Edition; SB-5, Stanford-Binet Intelligence Scales, Fifth Edition; VMI-6, Beery-Buktenica Developmental Test of Visual Motor Integration, Sixth Edition.

the mvASD group scored lower on all assessments compared to participants in the NT group. Scores on both language measures consistently fell below average for all mvASD participants, and five mvASD participants received a raw score of zero on the EVT-3. In contrast, there was greater variability in scores on measures of fine motor and nonverbal cognitive skills in the mvASD group. The majority of mvASD participants (91.2%) met criteria for intellectual disability (ABIQ < 70).

Correlation analyses

Spearman's correlations within each group are summarized in Table 3.

mvASD group

In the mvASD group, scores on the fine motor measures (GPT and VMI-6) were significantly correlated with each other [$r_s(32) = -0.662$, $p < 0.001$]. Scores on the language measures (EVT-3 and PPVT-5) were also significantly correlated with each other [$r_s(24) = 0.433$, $p = 0.027$]. Stronger fine motor skills were significantly correlated with higher EVT-3 scores [GPT: $r_s(29) = -0.385$, $p = 0.033$; VMI-6: $r_s(29) = 0.648$, $p < 0.001$], but not with PPVT-5 scores [GPT: $r_s(25) = 0.032$, $p = 0.874$; VMI-6: $r_s(25) = 0.208$, $p = 0.297$]. Similarly, higher SB-5 Nonverbal scores were significantly correlated with higher EVT-3 scores [$r_s(29) = 0.558$, $p = 0.001$], but not with PPVT-5 scores [$r_s(25) = 0.342$, $p = 0.081$]. SB-5 Nonverbal scores were significantly correlated with scores on both fine motor measures [GPT: $r_s(32) = -0.481$, $p = 0.004$; VMI-6: $r_s(32) = 0.537$, $p = 0.001$]. All findings survived correction for multiple comparisons ($ps < 0.005$), except for the correlation between EVT-3 and PPVT-5 scores and the correlation between GPT and EVT-3 scores.

NT group

In the NT group, scores on measures of fine motor skills (GPT and VMI-6) were not significantly correlated with each other [$r_s(27) = -0.330$, $p = 0.080$], while scores on measures of language abilities (EVT-3 and PPVT-5) were significantly correlated [$r_s(25) = 0.869$, $p < 0.001$]. Neither fine motor measure was significantly correlated with EVT-3 scores [GPT: $r_s(25) = -0.247$, $p = 0.214$; VMI-6: $r_s(25) = 0.365$, $p = 0.061$]. VMI-6 scores were significantly correlated with PPVT-5 scores [$r_s(25) = 0.404$, $p = 0.036$], although this finding did not survive correction for multiple comparisons. SB-5 Nonverbal scores were not significantly correlated with scores on measures of fine motor skills [GPT: $r_s(27) = 0.138$, $p = 0.476$; VMI-6: $r_s(27) = 0.209$, $p = 0.276$] or language abilities [EVT-3: $r_s(25) = 0.200$, $p = 0.318$; PPVT-5: $r_s(25) = 0.197$, $p = 0.324$].

SEM

Standardized (β) and unstandardized (b) parameter estimates for each group's model are presented in Table 4.

mvASD group

In the mvASD group, the model revealed a significant path between VMI-6 and EVT-3 scores ($\beta = 0.488/b = 2.976$, $p = 0.001$), indicating that mvASD participants with stronger fine motor skills had higher expressive language abilities. The model also revealed a significant path between SB-5 Nonverbal and PPVT-5 scores ($\beta = 0.724/b = 2.647$, $p < 0.001$), indicating that mvASD participants with stronger nonverbal cognitive skills had higher receptive language abilities. Age as a covariate was significantly associated with PPVT-5 scores ($\beta = -0.377/b = -1.776$, $p = 0.008$), and sex as a covariate was significantly associated with EVT-3 scores ($\beta = 0.290/b = 20.551$, $p = 0.007$), showing that older mvASD participants had lower receptive language abilities than younger mvASD participants, and female mvASD participants had higher expressive language abilities than male mvASD participants. GPT scores were not significantly associated with either language measure in the model ($ps \geq 0.085$). Overall, the model explained 50.5% of the variance in EVT-3 scores and 48.0% of the variance in PPVT-5 scores. Significant paths, covariances, and residual variances for the mvASD group's model are depicted in Figure 1.

TABLE 3 Spearman's correlations by group.

		Fine motor skills		Nonverbal cognitive skills	Language abilities	
		GPT	VMI-6	SB-5 Nonverbal	EVT-3	PPVT-5
mvASD						
Fine motor skills	GPT	1.00	–	–	–	–
	VMI-6	−0.662***	1.00	–	–	–
Nonverbal cognitive skills	SB-5 Nonverbal	−0.481**	0.537***	1.00	–	–
Language abilities	EVT-3	−0.385*	0.648***	0.558***	1.00	–
	PPVT-5	0.032	0.208	0.342	0.433*	1.00
NT						
Fine motor skills	GPT	1.00	–	–	–	–
	VMI-6	−0.330	1.00	–	–	–
Nonverbal cognitive skills	SB-5 Nonverbal	0.138	0.209	1.00	–	–
Language abilities	EVT-3	−0.247	0.365	0.200	1.00	–
	PPVT-5	−0.150	0.404*	0.197	0.869***	1.00

Bonferroni correction was used to account for multiple comparisons with an adjusted alpha level of $p = 0.005$. Correlations that did not survive correction for multiple comparisons are marked with *($p < 0.05$). Correlations that did survive correction for multiple comparisons are marked with ** ($p < 0.005$) or *** ($p \leq 0.001$). EVT-3, Expressive Vocabulary Test, Third Edition; GPT, Grooved Pegboard Test; mvASD, minimally verbal autism spectrum disorder; NT, neurotypical; PPVT, Peabody Picture Vocabulary Test, Fifth Edition; SB-5, Stanford-Binet Intelligence Scales, Fifth Edition; VMI, Beery-Buktenica Developmental Test of Visual Motor Integration, Sixth Edition.

NT group

In the NT group, the only significant path found in the model was between age and VMI-6 scores ($\beta = -0.405/b = -0.220$, $p = 0.016$), demonstrating that older NT participants had lower fine motor skills than younger NT participants. All other paths were non-significant ($ps \geq 0.075$).

Discussion

The current study is the first to examine the association between fine motor skills and language abilities in a sample of mvASD adults. Contrary to our hypotheses, stronger fine motor skills were significantly associated with higher expressive, but not receptive, language abilities in the mvASD group. Additionally, mvASD participants with stronger nonverbal cognitive skills had higher expressive language abilities, as well as stronger fine motor skills. When all variables were included within a single model, fine motor skills measured by the VMI-6 emerged as the best statistical predictor of expressive language abilities, while nonverbal cognition was the best predictor of receptive language abilities in the mvASD group. Together these findings suggest for mvASD adults, the motor system is involved in expressive language, while broader cognitive systems may play a more important role in receptive language. Furthermore, associations that were found in the mvASD group were not present in the NT group, which suggests that the motor-language association that is commonly found in NT children is not present in NT adults.

Fine motor skills predict expressive language abilities in mvASD adults

Correlation analyses demonstrated that for mvASD participants, scores on both measures of fine motor skills, were associated with scores on the EVT-3, our measure of expressive language. Nonverbal cognitive skills, as measured by the SB-5 Nonverbal subtest, were also associated with expressive language abilities in the mvASD group. These findings, which align with those reported in previous studies of children and adolescents with ASD (Butler and Tager-Flusberg, 2023; Luyster et al., 2008; Mody et al., 2017; Pecukonis et al., 2019; Simarro Gonzalez et al., 2024; Wu et al., 2021), indicate that mvASD participants with stronger fine motor and nonverbal cognitive skills also had stronger expressive language abilities. Once we accounted for the associations among all of these variables within a single model, we found that fine motor skills, as measured by the VMI-6, emerged as the best statistical predictor of expressive language abilities. This suggests that individual differences in fine motor skills, rather than nonverbal cognitive skills, explained most of the variability in expressive language abilities across participants in the mvASD group. Although the cross-sectional design of the present study limits our ability to draw conclusions about causality for the association between fine motor skills and expressive language abilities in mvASD adults, studies of autistic children and infants at elevated likelihood for ASD have shown that early motor skills are predictive of later language abilities (Bal et al., 2020; Choi et al., 2018; Hellendoorn et al., 2015; LeBarton and Iverson, 2013; LeBarton and Landa, 2019; Li et al., 2023), suggesting that there is some directionality to this relationship.

The association between fine motor skills and expressive language abilities observed in the present mvASD sample could be explained by broader impairments in the motor system. Atypical function of the motor system has been proposed as one possible cause of language impairments in ASD (Mody and McDougle, 2019), as several studies have documented reduced skills across fine motor, gross motor, and oromotor domains (Bhat, 2021; for review see Maffei et al., 2023; Wang et al., 2022). For mvASD participants in the current study, impairments in motor function may have impacted one's ability to produce spoken responses required by the EVT-3, resulting in poorer performance on this expressive language

TABLE 4 Parameter estimates for structural equation model by group.

mvASD			
	β/b	SE	p
Direct paths			
GPT→EVT-3	−0.039/−0.033	0.150	0.796
VMI-6→EVT-3	**0.488/2.976**	**0.146**	**0.001**
SB-5 Nonverbal→EVT-3	0.128/0.681	0.108	0.238
Age→EVT-3	−0.054/−0.372	0.167	0.746
Sex→EVT-3	**0.290/20.551**	**0.108**	**0.007**
GPT→PPVT-5	0.320/0.185	0.186	0.085
VMI-6→PPVT-5	0.078/0.329	0.208	0.706
SB-5 Nonverbal→PPVT-5	**0.724/2.647**	**0.159**	**<0.001**
Age→PPVT-5	**−0.377/−1.776**	**0.143**	**0.008**
Sex→PPVT-5	−0.024/−1.187	0.154	0.875
Age→GPT	−0.276/−2.256	0.146	0.059
Sex→GPT	−0.252/−21.282	0.168	0.133
Age→VMI-6	0.276/0.311	0.171	0.107
Sex→VMI-6	0.159/1.853	0.181	0.378
Age→SB-5 Nonverbal	0.266/0.343	0.169	0.116
Sex→SB-5 Nonverbal	0.143/1.909	0.187	0.443
Covariances			
PPVT-5↔EVT-3	0.097/38.895	0.186	0.602
VMI-6↔GPT	**−0.610/−116.917**	**0.127**	**<0.001**
SB-5 Nonverbal↔GPT	**−0.433/−95.887**	**0.140**	**0.002**
SB-5 Nonverbal↔VMI-6	**0.576/18.081**	**0.130**	**<0.001**
NT			
	β/b	SE	p
Direct paths			
GPT→EVT-3	−0.310/−0.289	0.174	0.075
VMI-6→EVT-3	0.186/0.945	0.185	0.316
SB-5 Nonverbal→EVT-3	0.171/0.748	0.184	0.352
Age→EVT-3	0.135/0.373	0.292	0.644
Sex→EVT-3	0.082/1.728	0.164	0.616
GPT→PPVT-5	−0.172/−0.147	0.165	0.298
VMI-6→PPVT-5	0.251/1.174	0.180	0.164
SB-5 Nonverbal→PPVT-5	0.147/0.590	0.154	0.340
Age→PPVT-5	0.132/0.335	0.331	0.689
Sex→PPVT-5	0.047/0.905	0.162	0.772
Age→GPT	0.133/0.394	0.180	0.461
Sex→GPT	−0.169/−3.791	0.174	0.332
Age→VMI-6	**−0.405/−0.220**	**0.169**	**0.016**
Sex→VMI-6	−0.256/−1.052	0.162	0.116
Age→SB-5 Nonverbal	0.067/0.043	0.133	0.611

(Continued)

TABLE 4 (Continued)

NT			
	β/b	SE	p
Sex→SB-5 Nonverbal	−0.181/−0.868	0.165	0.273
Covariances			
PPVT-5↔EVT-3	**0.899/75.819**	**0.035**	**<0.001**
VMI-6↔GPT	**−0.327/−6.640**	**0.165**	**0.048**
SB-5 Nonverbal↔GPT	0.044/1.129	0.171	0.796
SB-5 Nonverbal↔VMI-6	0.180/0.783	0.141	0.202

Significant direct associations are in bold. β represents standardized estimates and b represents unstandardized estimates. Standard error (*SE*) and *p*-values are also provided. ABIQ, abbreviated battery intelligence quotient; EVT-3, Expressive Vocabulary Test, Third Edition; GPT, Grooved Pegboard Test; mvASD, minimally verbal autism spectrum disorder; NT, neurotypical; PPVT, Peabody Picture Vocabulary Test, Fifth Edition; SB-5, Stanford-Binet Intelligence Scales, Fifth Edition; VMI-6, Beery-Buktenica Developmental Test of Visual Motor Integration, Sixth Edition.

measure. This behaviorally observed motor-language association in mvASD adults may be the result of alterations in shared neural systems (Willems and Hagoort, 2007), which should be explored in future work.

Nonverbal cognitive skills predict receptive language abilities in mvASD adults

Scores on the PPVT-5, our measure of receptive language, were not associated with scores on either fine motor measure in the mvASD group. While the association between SB-5 Nonverbal and PPVT-5 scores did not reach significance in our correlation analyses, our all-inclusive model revealed that this measure of nonverbal cognition was the best statistical predictor of receptive language abilities in the mvASD group. This finding demonstrates that individual differences in nonverbal cognitive skills explained most of the variability in receptive language abilities across mvASD participants. While other studies have similarly documented this association between nonverbal cognition and receptive language in children and adolescents with ASD (Charman et al., 2005; Chen et al., 2024; Haebig and Sterling, 2017; Luyster et al., 2008; Muller et al., 2022; Plesa Skwerer et al., 2016; Thurm et al., 2007), current findings conflict with previous work reporting significant and positive associations between fine motor skills and receptive language abilities in ASD (Mody et al., 2017; Simarro Gonzalez et al., 2024; Wu et al., 2021). For example, a recent study by Simarro Gonzalez et al. (2024) reported that higher VMI-6 scores were associated with higher EVT-3 and PPVT-5 scores in a sample of children and adolescents with ASD, 8 to 17 years old. This study also found that GPT scores were significantly associated with PPVT-5 scores, but not with EVT-3 scores (Simarro Gonzalez et al., 2024). These conflicting findings may be the result of differences in the ages and/or language abilities of autistic participants in each sample. One possibility is that the association between fine motor skills and receptive language abilities may differ for autistic individuals during childhood

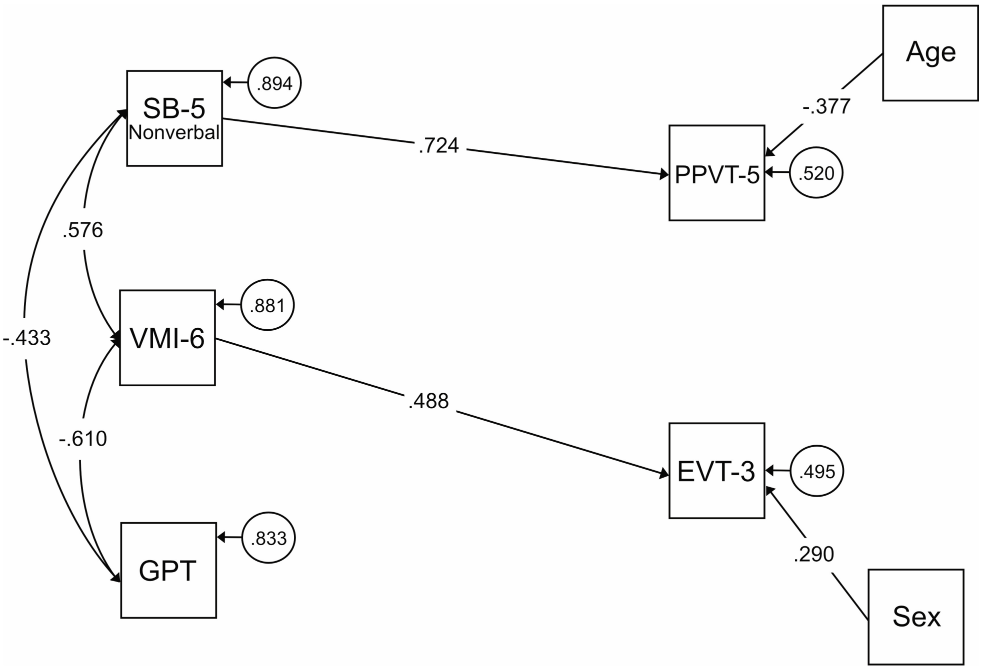

FIGURE 1
Model standardized estimates for significant paths (single headed arrows) and covariances (double headed arrows) for the mvASD group. Measures of fine motor skills, nonverbal cognitive skills, language abilities, and covariates are shown in squares. Residual variances are shown in circles. EVT-3, expressive vocabulary test; GPT, grooved pegboard test; PPVT-5, Peabody picture vocabulary test; SB-5, Stanford Binet; VMI-6, visual motor integration.

compared to adulthood. The non-significant association between fine motor skills and receptive language abilities that was found in the current sample of autistic adults could be the result of a developmental change in receptive language abilities during adulthood, similar to the impact of vocabulary growth on speech motor gestures in typical development (Edwards et al., 2004). For instance, it is possible that those with stronger receptive language abilities during childhood experience a relative decline in language abilities with age and discontinuation of targeted speech and behavioral therapy interventions, which could alter group-level associations between fine motor skills and receptive language abilities overtime. In support of this hypothesis, we did observe a negative association between age and PPVT-5 scores in our mvASD group, indicating that older autistic participants had lower receptive language abilities. This possible decline in receptive language abilities with age, which has also been documented in previous studies of mvASD individuals (Chen et al., 2024; Howlin et al., 2014), should be explored in future research.

Current findings suggest that for mvASD adults, nonverbal cognition plays an important role in language comprehension. Experiencing broader cognitive challenges with fluid reasoning (i.e., the ability to solve novel problems) may reflect more substantial global impairments that also impact one's ability to recognize patterns in language and learn the meaning of new words, ultimately resulting in a reduced receptive vocabulary. However, previous research has shown that cognition and language mutually influence each other throughout development (Kievit et al., 2017), and thus it is likely that receptive language abilities also have an impact on nonverbal cognitive skills. For example, mvASD participants in the current study with lower receptive language abilities may have had a more difficult time comprehending spoken directions provided during the SB-5 assessment, leading to poorer performance on this measure of nonverbal cognition. Future studies should utilize measures that are able to accurately capture nonverbal cognitive skills in mvASD adults without requiring participants to understand spoken directions, such as the Leiter Performance Scale (Roid et al., 2013), which has been shown to provide higher estimates of nonverbal cognitive skills for autistic individuals (Grondhuis and Mulick, 2013; Grondhuis et al., 2018).

Fine motor and nonverbal cognitive skills do not predict language abilities in NT adults

In contrast to the mvASD group, we did not find any associations between fine motor, cognitive, and language measures in the NT group. To our knowledge, this is the first study to demonstrate that the association between fine motor skills and language abilities, which has been well-documented in NT children, is not present in NT adults. It is believed that motor skills are critical for acquiring language during development, as they provide children with more opportunities to interact with and learn from their environment (Iverson, 2010). In NT children, stronger motor skills are associated with higher expressive and receptive language abilities during infancy and childhood, and can predict later language outcomes (Alcock and Krawczyk, 2010; Gonzalez et al., 2019; Libertus and Violi, 2016; Wang et al., 2014a,b). Although language and motor impairments are more commonly found in autistic children compared to their NT peers, this motor-language association has been documented across groups of NT children, autistic children, and infants at elevated likelihood for ASD (Choi et al., 2018; LeBarton and Iverson, 2013). It remains unclear how the relationship between fine motor skills and language abilities changes throughout development, particularly into adolescence and adulthood. However, a series of studies by Wang and colleagues showed that motor skills measured in 1.5 year old NT children significantly predict language abilities at 3 years of age (Wang et al., 2014a), but motor skills in 3 year old NT children did not predict language skills at 5 years of age (Wang et al., 2014b), indicating that the link between motor skills and language abilities is stronger in younger children. A recent study by Simarro Gonzalez et al. (2024) also reported non-significant associations between fine motor and language measures in a sample of older NT children and adolescents, suggesting that this motor-language association decouples with age, perhaps as spoken language proficiency increases (e.g., Redford and Oh, 2017). Additional work is needed to understand how this motor-language association changes throughout development, and whether the trajectory of this relationship differs between individuals with and without ASD.

Limitations and future directions

Although interesting relationships between fine motor skills, nonverbal cognitive skills, and language abilities emerged from the present study, it is important to note that these results were in a relatively small sample that lacks sufficient racial, ethnic, and socioeconomic diversity, and therefore may not be representative of the broader population. Our sample size prevented us from using more complex structural equation modeling techniques, such as factor analysis. It also impacted the number of variables that we were able to include in our model. For example, we were unable to investigate how measures of attention and social skills might impact the associations between motor, cognitive, and language measures. Coupled with limited variability on some measures (e.g., VMI-6), our smaller sample size could also explain why we observed non-significant correlations in the NT group.

This study utilized a battery of standardized neuropsychological assessments that are commonly used in clinical and research settings. However, using these assessments with mvASD adults poses some challenges (Tager-Flusberg et al., 2017). First, these assessments were primarily designed for and normed using NT samples, and therefore standardized administration and scoring (e.g., beginning with "age-appropriate" items and assuming all items before an established basal would be answered correctly) may not provide an accurate estimate of abilities in mvASD. Second, using standard scores in mvASD samples often results in floor effects, especially on measures of expressive language. While using raw scores in our analyses increased within-group variability, it also prevented us from comparing performance across measures (e.g., EVT-3 vs. PPVT-5 scores). Third, all assessments required participants to understand spoken directions, which may have led to an underestimation of fine motor and cognitive skills in the mvASD group. Assessments that do not require verbal exchange between participants and the examiner, such as the Leiter Performance Scale (Roid et al., 2013), may be better suited for capturing nonverbal cognitive abilities in this population; however, entirely nonverbal measures of language skills do not exist. Lastly, standardized assessments may not capture the full potential of language abilities in mvASD. For example, the EVT-3 measures an individual's single word expressive vocabulary, but does not provide information about the use of more complex phrase speech or non-spoken communication abilities. Natural language sampling may be an alternative way to obtain a more accurate measure of expressive language abilities in mvASD (Barokova and Tager-Flusberg, 2020; Chenausky et al., 2023).

Despite these limitations, the present study adds an important contribution to the limited literature on mvASD adults. Findings provide novel insights into the role that fine motor and nonverbal cognitive skills play in the production and comprehension of spoken language in mvASD. Future studies should aim to replicate these findings in a larger and more diverse sample, ideally using a longitudinal study design. Greater efforts should also be made to design assessments and other study procedures that are inclusive of mvASD adults in research.

Clinical implications

Current findings have important implications for the design of clinical interventions for mvASD adults. The positive association between fine motor skills and expressive language abilities suggests that incorporating activities that strengthen fine motor skills into interventions may help to improve spoken language. To the extent that babbling and early speech gestures pave the way for phonological development, interventions that target awareness of vocal production through auditory feedback may enhance spoken language abilities (Iuzzini-Seigel et al., 2015). Previous studies have documented improvements in autistic children's language and communication abilities after the completion of therapy targeting motor functions (e.g., reciprocal imitation therapy; McCleery et al., 2013; Odeh et al., 2020), although further research is needed to determine whether mvASD adults would benefit from similar interventions. Additionally, our findings suggest that mvASD adults with lower expressive language abilities may also have reduced fine motor skills, which could impact their ability to utilize existing forms of augmentative and alternative communication (AAC), including speech-generating devices and manual sign language, both of which require use of the hands and fingers. Further work is needed to explore how existing forms of AAC can be adapted to fit the motoric needs of mvASD adults.

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 humans were approved by the Mass General Brigham Institution Review Board as part of the Human Research Protection Program. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

Author contributions

MP: Validation, Data curation, Visualization, Conceptualization, Methodology, Writing – review & editing, Investigation, Formal analysis, Writing – original draft. PHT: Validation, Data curation, Visualization, Conceptualization, Methodology, Writing – review & editing, Investigation, Formal analysis, Writing – original draft. LS: Investigation, Writing – review & editing, Project administration, Validation, Methodology, Data curation. CJ: Writing – review & editing, Methodology. NK: Investigation, Methodology, Writing – review & editing. NP: Methodology, Investigation, Writing – review & editing. JW: Methodology, Writing – review & editing. SY: Writing – review & editing, Methodology. PM: Writing – review & editing, Methodology. TQ: Methodology, Writing – review & editing. CM: Methodology, Conceptualization, Resources, Supervision, Writing – review & editing, Funding acquisition. MM: Writing – review & editing, Supervision, Funding acquisition, Resources, Project administration, Conceptualization, Methodology. LN: Investigation, Resources, Conceptualization, Supervision, Funding acquisition, Writing – review & editing, Project administration, Methodology.

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