Associations between Manual Dexterity and Language Skills Persist into Adulthood

Patricia J. Brooks, Rita Obeid, and Alexandria Garzone

1. Introduction

Motor skills and language acquisition show linkages from early infancy (Iverson, 2010; Iverson & Thelen, 1999). Infants appear to coordinate their babbling with rhythmic arm movements starting at ages 6 to 9 months (Iverson & Fagan, 2004). In a large-scale longitudinal study involving 62,944 mothers and their infants (Wang et al., 2012), language and motor skills correlated strongly at 18 months ($r = .72$), as assessed via maternal report. Notably, infants' motor skills at 18 months predicted their language abilities at age 3 years, whereas their language abilities at 18 months were negatively associated with motor skills at age 3. Such findings suggest that motor skills support language acquisition at early stages of development rather than vice versa.

Infants communicate with gestures (e.g., pointing, waving) prior to producing their first words (Bates et al., 1979) with their first words tending to map onto entities previously referenced via gesture (Iverson & Goldin-Meadow, 2005). At the outset of combinatorial, multiword speech, infants use gesture-word combinations (e.g., saying *more* while pointing to desired object) prior to expressing similar intentions with two-word utterances (Capirci et al., 1996; Iverson & Goldin-Meadow, 2005). Other work has linked word representations with gesture at the level of neurocognitive processing. For example, fMRI studies indicate activation of motor and premotor cortex as individuals process verbs and other action-related terms (Hauk et al., 2004). Evidence that passively listening to "foot" versus "hand" verbs (e.g., *jump* vs. *throw*) differentially activates cortical areas associated with actual movements of the hands or feet has been extended to children as young as 4 to 6 years of age (James & Maouene, 2009). Such findings support embodied models of cognition emphasizing the role of sensorimotor experience in cognitive development (Barsalou, 2008; Yu & Smith, 2012).

Clinical research indicates that children with language impairments often exhibit concomitant deficits in motor skills (Cheng et al., 2009; Hill, 2001). Findings of comorbid motor impairments in developmental dyslexia (Fawcett &

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Nicolson, 1995; Ramus et al., 2003) are thought to reflect underlying deficits in automaticity and anticipatory processing (Pagliarini et al., 2020). Ullman's (2001, 2004) declarative/procedural model of language (shown in Figure 1) offers a theoretical account of such relations by suggesting that both motor skills and rule-based aspects of language (phonology and grammar) rely heavily on the frontal/striatal/cerebellar circuits that support procedural learning, especially Broca's area within the frontal cortex and the caudate nucleus within the basal ganglia. According to procedural deficit hypothesis (Ullman & Pierpont, 2005), individuals with developmental language disorder have domain-general difficulties in learning sequential patterns and in constructing the complex hierarchical (syntactic) representations on which language processing and action planning depend (Fitch & Martins, 2014; Koranda et al., 2020). This hypothesis is supported by recent meta-analyses indicating impaired motor skills (Rechetnikov & Maitra, 2009) and statistical learning of sequential information in developmental language disorder (Lammertink et al., 2017; Obeid et al. 2016) and dyslexia (Lum et al., 2013).

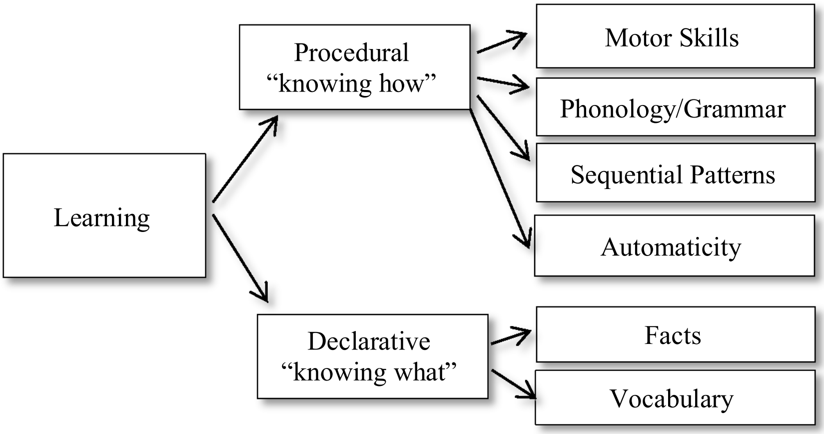

Fig. 1. Ullman's (2001; 2004) declarative/procedural model

Outside of clinical research on developmental language disorder and dyslexia, only a handful of studies have examined individual differences in motor skills in relation to the language abilities of children, adolescents, or adults. To date, most studies have focused on reading and have generated mixed results. In a longitudinal study, Doyen et al. (2017) used a pegboard task to assess manual dexterity of 73 kindergarten children in relation to their reading abilities at the end of first grade. After controlling for phonological processing skills, manual dexterity in using the non-dominant hand and weaker lateralization (i.e., difference between hands) predicted children's subsequent reading and spelling skills one year later. Using data from 12,583 children who participated in the Early Childhood Longitudinal Study (Tourangeau et al., 2002), Son and Meisels (2006) also found that visual motor skills in kindergarten predicted reading skills at the end of first grade. In a recent study involving adults, Franceschini et al. (2021) documented a positive association between motor skills acquisition (i.e., improved performance on the pegboard task across sessions) and fluency in nonword reading. In contrast, manual dexterity was not associated with word reading ability and was negative associated with fluency in decoding nonwords.

Moving beyond reading, Obeid and Brooks (2018) examined manual dexterity in relation to phonological short-term memory and receptive language abilities in a community sample of school-age children (6- to 10-year-olds). Faster completion times on the pegboard task were associated with higher accuracy in nonword repetition—a widely used index of phonological short-term memory capacity and phonological representations in studies of developmental language disorder (Estes et al., 2007; Rispens & Baker, 2012). Additionally, manual dexterity was indirectly related to receptive vocabulary and grammatical knowledge, with the effects mediated by nonword repetition. To find out whether the observed relations persisted into adulthood, the current study tested college students using the same methodology. Our research questions were as follows:

1. Is manual dexterity associated with individual differences in nonword repetition, receptive vocabulary, and receptive grammar in adults?
2. Do the associations remain significant after controlling for individual differences in nonverbal abilities?
3. Are the associations between manual dexterity and receptive language abilities (vocabulary and grammar) direct or indirect, i.e., mediated by nonword repetition?

2. Method

2.1. Participants

Sixty-five undergraduates (46 women, 19 men; *M* age = 20 years, *SD* = 2.5, *range* 18–30; 89% right-handed) took part in this study. The data were collected at an urban public university with a lenient open-admissions policy, allowing us to test adults with a wide range of language and nonverbal abilities. Participants were recruited through a subject pool and received course research credits as compensation. All of the participants were native speakers of English. Participants reported race/ethnicity as follows: White (37.5%), Black/African American (18.8%). Middle Eastern (17.2%), Latino/a (7.8%), Asian (4.7%), Other (3.1%), and Mixed (10.9%).

For comparison, we used previously reported data from school-age children (Obeid & Brooks, 2018). The child sample comprised sixty-three children (33 girls, 30 boys; *M* age = 8 years; 2 months, *SD* = 1;3, *range* 6;0–10;8; 92% right-handed). All children were native speakers of American English. Parents reported child race/ethnicity as follows: White (63.5%), Black/African American (12.7%), Middle Eastern (6.3%), Latino/a (4.8%), Asian (1.6%), and Mixed (11.1%).

2.2. Measures

2.2.1. Grooved Pegboard Task

We administered the Grooved Pegboard task as an assessment of manual dexterity (Model #32025; Lafayette Instrument Company, 1989). Participants were seated in front of a pegboard with 25 key shaped holes organized in a 5 x 5 matrix. They were instructed to take one peg at a time from a circular receptacle where all pegs were placed and put it in a hole by rotating the peg to match the shape of the hole. Participants had to complete this task using their dominant and non-dominant hand in a counterbalanced order. Completion time in seconds was measured using a stop-watch. For both groups, there was a strong correlation between completion times for the dominant and non-dominant hand, adults: $r(63) = .71, p < .001$; children: $r(61) = .72, p < .001$. To compute the manual dexterity scores, we averaged completion times for the two hands.

2.2.2. Nonword Repetition Test

The nonword repetition test was used to assess phonological short-term memory. The test was adapted from Edwards et al. (2004) and Munson et al. (2005) and run on an Acer laptop computer using E-Prime 2.0 software (Schneider et al., 2002). The nonword stimuli consisted of thirty 3- and 4- syllable non-words (e.g., /hesɚləm/, /mæsɚtɑlən/), recorded by a female native speaker of English, and presented via external speakers. The nonwords were arranged in two blocks of 15 trials and presented in a randomized order. Participants were instructed to repeat the nonword when a blue fixation cross appeared on the computer screen, 100ms after the offset of the nonword. Responses were audio-recorded and scored as correct or incorrect. To establish coding reliability, two independent research assistants coded 20% of the data. Interrater agreement was at 94%. In the analyses reported, we used arcsine transformed proportions of correct responses as the outcome variable.

2.2.3. Peabody Picture Vocabulary Test

We administered the Peabody Picture Vocabulary Test–Fourth Edition (PPVT–4; Dunn & Dunn, 2007) as a norm-referenced, untimed assessment of receptive vocabulary knowledge. The participant is seated in front of the experimenter with the test easel between them. On each trial, they are shown a page with four pictures and instructed to pick the one that matched a word spoken aloud by the experimenter. Trials are arranged in sets of increasing difficulty with the initial set determined by the participant's age. The test is terminated after a specified number of errors are made on a given set. We calculated standardized scores for the PPVT–4 based on population norms ($\mu = 100$, $\sigma = 15$). However, for the statistical analyses reported here, we used raw scores to avoid interpretive issues that arise when entering a mixture of standardized and non-standardized (raw) scores into the same models.

2.2.4. Test for the Reception of Grammar

The Test for the Reception of Grammar–Second Edition (TROG–2; Bishop, 2003) provided a norm-referenced, untimed assessment of grammatical knowledge. Similar to the PPVT–4 in format, participants are seated across from the experimenter with the test easel between them. On each trial, they are shown four pictures on a page, depicting objects or scenes. The participant is instructed to point to the picture that matches a sentence read aloud by the experimenter. Participants are tested four times each on 20 grammatical contrasts (80 trials in total), with the maximum raw score = 20. We derived standardized scores for each participant ($\mu = 100$, $\sigma = 15$), but used the raw scores in the analyses.

2.2.5. Test of Nonverbal Intelligence

We used the Test of Nonverbal Intelligence–Third Edition (TONI–3; Brown et al., 1997) as a language-free measure of intelligence, aptitude, reasoning, and problem solving. This standardized assessment consists of 60 items, arranged in an order of increasing difficulty. On each trial, the participant is shown an incomplete visual-spatial array and given 4 to 6 alternative shapes to complete the pattern. Trials progress until the participant has made a specified number of errors. We derived standardized scores for each participant based on population norms ($\mu = 100$, $\sigma = 15$), but used the raw scores in the analyses.

2.3. Procedure

Participants were tested individually in a research laboratory. Adults were tested in a single 2-hour session whereas children were tested over two sessions to reduce fatigue. Participants completed the grooved pegboard task, the nonword repetition test, and the standardized assessments of receptive vocabulary, receptive grammar, and nonverbal intelligence in a randomized order. Trained research assistants (including the second and third authors) administered and scored the tests.

3. Results

3.1. Descriptive Statistics

Table 1 presents descriptive statistics for the two age groups. The adults were faster than the children in completing the grooved pegboard task, $t(109.65) = 6.75$, $p < .001$, but unexpectedly did not differ in accuracy on the nonword repetition test, $t(126) = .49$, $p = .45$. Although the adults tended to have higher raw scores than the children on the three norm-referenced tests (PPVT–4, TROG–2, TONI–3), the children tended to have higher standardized scores on all three tests, $ps \leq .001$. Average standardized scores for the adult sample were slightly below the population mean of 100, whereas the average standardized scores for the children were well above the population mean. However, as indicated in Table 1, there were substantial individual differences in performance on the tasks. Both the adult and child samples exhibited a wide range of scores on each of the assessments, with a considerable degree of overlap in the distributions of scores on all measures for the two age groups.

Table 1. Mean scores for verbal and nonverbal assessments. All standard deviations in parentheses (*N* = 65 for adults, *N* = 63 for children).

		Raw Scores		Standardized Scores	
Task	Domain	*M* (*SD*)	Range	*M* (*SD*)	Range
Adults					
Grooved Pegboard	Manual Dexterity	72.2 sec (16.7)	54.1–161.7	n/a	
Nonword Repetition	Phonological Short-Term Memory	68.9% (15.3)	23.3–93.3	n/a	
PPVT–4	Receptive Vocabulary	192.1 (17.0)	154–221	98 (16)	71–136
TROG–2	Receptive Grammar	16.8 (2.6)	9–20	94 (12)	58–109
TONI–3	Nonverbal Intelligence	25.6 (7.9)	7–42	93 (14)	67–130
Children					
Grooved Pegboard	Manual Dexterity	98.2 sec (24.3)	60.6–166.0	n/a	
Nonword Repetition	Phonological Short-Term Memory	70.8% (14.2)	36.7–96.7	n/a	
PPVT–4	Receptive Vocabulary	146.4 (22.0)	90–183	113 (16)	72–146
TROG–2	Receptive Grammar	14.9 (3.5)	5–20	102 (16)	62–130
TONI–3	Nonverbal Intelligence	20.9 (6.6)	4–34	114 (14)	81–144

Note. PPVT–4 = Peabody Picture Vocabulary Test, Fourth Edition; TROG–2 = Test for the Reception of Grammar, Second Edition; TONI–3 = Test of Nonverbal Intelligence, Third Edition

3.2. Correlational Analyses

Table 2 shows the zero-order bivariate correlations across measures for adults (bottom left) and children (top right). Note that we used the raw scores for each of the norm-referenced tests (PPVT–4, TROG–2, TONI–3). Children, but not adults, showed significant correlations with age on measures of manual dexterity (pegboard), receptive vocabulary (PPVT–4), and nonverbal intelligence (TONI–3), indicating age-related increases in abilities from 6 to 10 years of age. For children, performance on the pegboard task correlated with all of the other measures, with faster completion times associated with higher scores on measures of phonological short-term memory (nonword repetition), receptive vocabulary, receptive grammar, and nonverbal intelligence. The same pattern obtained for the adults, with the exception that the correlation between pegboard completion times and TONI–3 raw scores, assessing nonverbal ability, was not significant.

Table 2. Bivariate correlations for adults (bottom left diagonal) and children (top right diagonal)

	Age	Pegboard	NW Rep	PPVT–4	TROG–2	TONI–3
Age	—	–.50*	.29	.49*	.27	.45*
Pegboard	–.06	—	–.42*	–.48*	–.42*	–.46*
NW Rep	.17	–.35*	—	.55*	.49*	.23
PPVT–4	.22	–.44*	.35*	—	.70*	.52*
TROG–2	.04	–.44*	.32	.45*	—	.59*
TONI–3	.23	–.19	.39*	.61*	.42*	—

Note. NW Rep = nonword repetition; PPVT–4 = Peabody Picture Vocabulary Test, Fourth Edition; TROG–2 = Test for the Reception of Grammar, Second Edition; TONI–3 = Test of Nonverbal Intelligence, Third Edition; $^*p < .0024$ Bonferroni-adjusted alpha.

3.3. Regression Analyses

To examine whether performance on the pegboard task predicted language skills in adults, we conducted a series of regression models; see Table 3 for results. In the first model, age and pegboard completion times were entered as predictor variables with each of the language measures (nonword repetition, PPVT–4, TROG–2) entered in a separate regression analysis as the outcome variable. In the second model, TONI–3 raw scores were added as a predictor in addition to age and pegboard completion times, to determine whether the results held when controlling for individual differences in nonverbal ability.

In both Model 1 and Model 2, pegboard completion times predicted raw scores on each of the language measures. Thus, even after controlling for significant effects of nonverbal intelligence on the outcome variables, individual differences in manual dexterity were associated with phonological short-term memory, receptive vocabulary, and receptive grammatical knowledge in adults.

Table 3. Standardized coefficients for regression models predicting language outcomes of adults (*N* = 65)

	Outcome Variables		
Predictors	NW Rep	PPVT–4	TROG–2
Model 1			
Age	.15	.20	.02
Pegboard	–.33**	–.43***	–.44***
R^2 Total	.14	.23	.20**
F (2, 62)	4.96**	9.30***	7.51**
Model 2			
Age	.08	.08	–.06
Pegboard	–.27*	–.33**	–.38**
TONI-3	.32*	.53***	.36**
R^2 Total	.23	.49	.31
F (1, 61)	7.56**	30.30***	10.57**

**p* < .05, ***p* < .01, ****p* < .001

Table 4. Standardized coefficients for regression models predicting language outcomes of children (*N* = 63)

	Outcome Variables		
Predictors	NW Rep	PPVT–4	TROG–2
Model 1			
Age	.11	.33*	.08
Pegboard	–.37**	–.32*	–.38**
R^2 Total	.19	.31	.18
F (2, 62)	6.84**	13.48***	6.66**
Model 2			
Age	.10	.24	–.07
Pegboard	–.36*	–.22	–.22
TONI-3	.03	.31*	.53***
R^2 Total	.19	.38	.38
F (1, 61)	.03	6.79*	19.21***

Note: This regression table has been adapted from Obeid & Brooks (2018)
**p* < .05, ***p* < .01, ****p* < .001

The results for the adult sample contrast with the previously reported findings of Obeid and Brooks (2018) for the child sample; see Table 4. For the child sample, pegboard completion times predicted language outcomes in Model 1. However, when TONI–3 raw scores were included as an additional predictor in Model 2, the effect of manual dexterity on receptive vocabulary (PPVT–4) and receptive grammar (TROG–2) were no longer significant. In contrast, pegboard completion times remained a significant predictor of phonological short-term memory (nonword repetition) after controlling for individual differences in nonverbal ability.

3.3.1. Mediation Analyses

To determine whether manual dexterity had a direct or indirect relation to receptive language abilities, we conducted mediation analyses using the PROCESS macro in SPSS (Hayes & Preacher, 2014). For both the adult and child data, receptive vocabulary and grammar (PPVT–4 and TROG–2 raw scores) were entered into the model as outcome variables, nonword repetition accuracy was entered as the mediator variable, and manual dexterity was entered as the predictor variable. Additionally, nonverbal intelligence and age were added into the model as covariates. We used a bootstrap estimation approach with 1,000 samples and 95% confidence intervals.

For adult sample, the mediation analyses confirmed that the relation between manual dexterity and receptive language scores was direct. There was no evidence of a significant indirect effect of manual dexterity, mediated by nonword repetition, in predicting adult receptive vocabulary, $\beta = -.007$, *CI* [–0.08, 0.06], or grammar scores, $\beta = -.003$, *CI* [–0.02, 0.01].

For the child sample, the mediation analyses indicated significant indirect effects of manual dexterity on receptive language abilities, depicted in Figure 2. The indirect effects mediated by nonword repetition were significant for both receptive vocabulary, $Z = -2.06$, $p = .039$; $\beta = -.14$, *CI* [–0.31, –0.03]. and receptive grammar, $Z = -2.00$, $p = .046$; $\beta = -.13$, *CI* [–0.29, –0.02]. These results suggest a direct link between motor skills and phonological short-term memory (phonological representations) which, in turn, may impact development of receptive vocabulary and grammatical knowledge.

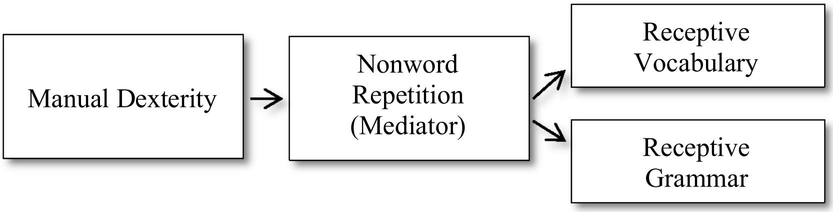

Fig 2. Indirect effects of manual dexterity on receptive vocabulary and grammar in the child sample, mediated by nonword repetition

4. Discussion

The idea that motor skills support language acquisition is widely shared across neurolinguistic and developmental frameworks (Hamrick et al., 2018; Iverson & Thelen, 1999; Leonard & Hill, 2014; Lieberman, 1985, 2000). Evidence of associations between motor and language skills comes from work on infant development (Iverson, & Fagan, 2004; Iverson, 2010) and clinical research on co-occurring motor and language impairments in children (Rechetnikov & Maitra, 2009). However, with few exceptions (Franceschini et al. 2020), researchers have not explored whether motor and language abilities remain linked beyond childhood.

The current study used the methodology of Obeid and Brooks (2018) to examine individual differences in college students' manual dexterity and language abilities. In the previous study, 6- to 10-year-olds' manual dexterity (pegboard completion time) was associated with their nonword repetition accuracy after controlling for age and nonverbal intelligence (TONI–3 scores). Manual dexterity was indirectly related to receptive vocabulary and grammatical knowledge, mediated by nonword repetition accuracy. The results were interpreted as support for neurolinguistic theories emphasizing connections between phonological abilities, motor control, and articulatory gestures (Lieberman, 1985, 2000) and a common neural substrate supporting procedural learning across motor and linguistic domains (Ullman, 2001, 2004).

In the adult study, the associations between motor and language skills were more direct than in the child study (Obeid & Brooks, 2018). In adults, manual dexterity was associated with nonword repetition accuracy, receptive vocabulary, and receptive grammatical knowledge after controlling for age and nonverbal ability. Mediation analyses indicated significant direct associations between manual dexterity and receptive language abilities, with no evidence of mediation by nonword repetition. The observed differences in the results for the child and adult studies might reflect long-term memory consolidation making linguistic representations more stable over time or it might be an artifact of features of the dataset (e.g., more adults than children had low-scores on norm-referenced tests). Although the adults were college students, it is possible that some of them may have had a history of motor and language difficulties that was not reported to us, potentially inflating the effects.

As our studies assessed receptive vocabulary and grammar knowledge, but not expressive language abilities, additional work is needed to understand how motor skills may differentially impact language production and comprehension. Early motor control would facilitate acquisition of the articulatory routines and sequential representations that underlie speech production (Fitch & Martins, 2014). However, with feedback systems linking speech perception and production from infancy (Bruderer et al. 2015), the sequential representations used to maintain information in phonological short-term memory would be expected to have broad impact on development of both expressive and receptive language abilities (Baddeley et al. 1989).

In the child study, but not the adult study, pegboard completion times were associated with TONI–3 raw scores. As an untimed assessment of nonverbal ability, the TONI–3 relies on visual-spatial attention and analysis, which may account for the observed correlation with the pegboard task. Although we have interpreted pegboard completion times as reflecting manual dexterity, the task is not likely to be pure measure of this construct. Franceschini et al. (2020) administered the closely related Purdue pegboard task to adults twice and noted markedly faster responses when the task was repeated. This suggests that procedural learning of the task itself affects performance over successive trials (e.g., dominant hand followed by nondominant hand). Observed variation in strategies for completing the 5 x 5 grid suggests that visual-spatial attention, action planning, and hand-eye coordination may affect performance in addition to manual dexterity; see also Bryden et al. (2007). Further research and task analysis is needed to understand the neurocognitive processes that account for shared variance between the pegboard task and the TONI–3. Such studies may indicate that links between motor skills and nonverbal abilities are stable over time or, as suggested by our findings, stronger in childhood.

In sum, our findings add to the literature by demonstrating that links between motor skills and language abilities persist into adulthood. The findings provide further evidence for the view that domain-general mechanisms support the operations that underlie automaticity in language processing and action planning.

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