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Motor Control and Nonword Repetition in Specific Working Memory Impairment and SLI

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Abstract

Purpose—Debate around the underlying cognitive factors leading to poor performance in the repetition of nonwords by children with developmental impairments in language has centered around phonological short-term memory, lexical knowledge, and other factors. The present study examined the impact of motor-control demands on nonword repetition in groups of school children with specific impairments in either language, working memory, or both.

Method—Children repeated two lists of nonwords matched for motoric complexity either without constraint, or with a gummi bear bite block held between their teeth. The bite block required motoric compensation to reorganize the motor plan for speech production.

Results—Overall, the effect of the biomechanical constraint was very small for all groups. When analyses focused only on the most complex nonwords, children with language impairment were found to be significantly more impaired in the motorically constrained nonword repetition task than the typically developing group. In contrast, working memory difficulties were not differentially linked to motor condition.

Conclusions—These findings add to the growing evidence that there is a motoric component to developmental language disorders. The results also suggest that the role of speech motor skill in nonword repetition is relatively modest.

Keywords

specific language impairment; working memory; nonword repetition; motor speech; short-term memory

Difficulty repeating novel phonological sequences immediately after hearing them, or poor nonword repetition, has become a hallmark of the developmental language delay known as Specific Language Impairment (SLI; e.g., Archibald & Gathercole, 2006; Conti-Ramsden, Botting & Faragher, 2001; Dollaghan & Campbell, 1998; Gray, 2003). This finding has sparked considerable interest in the cognitive processes tapped by nonword recall as it may reveal the underlying impairment that predisposes children to SLI. Debate has centered around whether nonword repetition is a relatively pure index of phonological short-term

memory (Gathercole & Baddeley, 1993) or is influenced also by linguistic knowledge such as that reflected in measures of vocabulary size (Snowling, Chiat & Hulme, 1991), the quality (Edwards, Beckman & Munson, 2004) or retrieval (Leclercq, Maillart, & Majerus, this volume) of sublexical phonological representations, or the influence of native-language phonotactics (Windsor, Kohnert, Lobitz, & Pham, 2010).

While the influence of motor speech skills on the different levels of nonword repetition accuracy in children with and without SLI has been acknowledged (Lahey & Edwards, 1998; Wells, 1995), it has received considerably less systematic investigation. It is logically possible that increases in demands on motor control in a nonword repetition task could affect repetition accuracy either directly or indirectly. An increase in motor-control demands could result in less accurate repetition, an effect that may have a disproportionate impact on children with SLI because of motor-control difficulties (Goffman, 1999, 2004). Alternatively, the influence may be indirect; for instance an increase in motor-control demands may place additional processing demands on working memory, leading to marked difficulties in repeating nonwords. The purpose of the present study was to examine the relationship between language, working memory, and motor speech skills in nonword repetition for groups of children with deficits in language and/or working memory as well as those with typical language and memory.

One influential view holds that nonword repetition is a measure of an individual's ability to briefly store phonological information in mind (Gathercole & Baddeley, 1993). Consistent with this assertion, nonword repetition performance is highly correlated with more conventional measures of phonological short-term memory such as digit span (Gathercole, Willis, Emslie & Baddeley, 1994), and is characterized by the primacy and recency effects that are present in other serial recall tasks (Archibald & Gathercole, 2007; Gupta, 2003). The use of unfamiliar stimuli – ‘nonwords’ – in a repetition task is an important element of the phonological short-term memory account. It is argued that the unfamiliarity of the phonological structure of nonwords requires greater reliance on retention of temporary phonological representations, preventing reliance on activated lexical representations as is possible in other serial recall tasks employing familiar verbal stimuli (Hulme, Maughan & Brown, 1991).

Phonological short-term memory refers to the brief storage of phonological information in the immediate memory system known as working memory. Working memory involves the temporary storage and controlled processing of information held in the current focus of attention (Baddeley & Hitch, 1974; Cowan, 2001; Engle, Kane & Tuholski, 1999). Most theoretical accounts of working memory expect some tradeoff between retention accuracy and processing load such that as processing demands increase, stored information may degrade (Barrouillet, Bernadin & Camos, 2004; Daneman & Carpenter, 1980). Standard nonword recall tasks requiring immediate repetition are considered to present minimal processing challenges and tap temporary storage abilities only. Manipulations that impose greater processing demands in addition to the nonword repetition such as requiring sentence comprehension (Marton & Schwartz, 2003) or including misleading coarticulatory cues (Archibald, Gathercole & Joanisse, 2009) result in less accurate recall. Thus, it can be expected that individuals who have particularly limited capacity to coordinate processing

and storage demands in working memory may perform more poorly on nonword recall tasks incorporating a processing load than in standard nonword repetition.

Nonword repetition deficits have been consistently reported for SLI groups from preschool (Gray, 2003) through to adolescence (Conti-Ramsden et al., 2001; Stothard, Snowling, Bishop, Chipchase & Kaplan, 1998). While some have argued that this finding provides evidence of a core phonological short-term memory impairment in this population (Gathercole & Baddeley, 1990), others have suggested that the impoverished linguistic skills of this group account for their poor nonword repetition (Snowling et al., 1991; van der Lely & Howard, 1993). According to this view, nonword repetition is simply another measure, albeit a good one, of the language deficits of this group particularly in the realm of phonological processing (Bowey, 2006; Chiat, 2006). Nonword repetition is recognized as a complex task involving several components, most involving phonological processing. At minimum, these include the perception of the phonemes that comprise the nonword; the construction, encoding, maintenance, and retrieval of a phonological representation; the assembly of articulatory instructions to replicate the nonword; and executing those commands. It has been suggested that nonword repetition consistently identifies SLI because any particular child with SLI may be impaired in at least one of these processes (Archibald & Gathercole, 2006; Ellis Weismer & Edwards, 2006).

In addition to phonological short-term memory and linguistic skills, nonword repetition accuracy may be influenced by the quality of speech output processes (Lahey & Edwards, 1998; Wells, 1995). Nevertheless, the motoric demands of nonword repetition have received very little research attention. Children with SLI have been reported to be especially impaired in repeating nonwords containing consonant clusters, which are thought to place greater demands on speech output processes due to the need to coordinate a variety of articulatory gestures within a syllable. This is true both when the children with SLI are compared to typically developing children (Archibald & Gathercole, 2006; Bishop et al., 1996; Briscoe, et al., 2001) and to children with hearing impairment (Briscoe et al., 2001). However, the error patterns of speakers with misarticulations on a syllable repetition task were not found to be associated with number of feature differences between a target and repeated consonant (Shriberg, Lohmeier, Campbell, Dollaghan, Green & Moore, 2009).

To our knowledge, no studies have investigated whether children with and without SLI are differentially affected by task manipulations that increase motor demands in a nonword task. The small body of research that has examined the influence of motor control on the nonword repetitions of children with SLI has focused either on their kinematic variability, or on the differential effects of prosody. Goffman (1999, 2004) showed that children with SLI produce speech with greater trial-to-trial kinematic variability than children with typical development. Goffman, Gerken, and Lucchesi (2007) showed that children with and without SLI repeat nonwords with greater motor variability than adults, though no significant differences between the two groups of children were noted. In related studies, we examined motoric effects by comparing performance on sets of nonwords that presumably differed in their intrinsic motor demands. For example, we compared repetition of multisyllabic nonword sequences and single syllables presented one per second in both typically-developing school age children (Archibald & Gathercole, 2007) and healthy adults

(Archibald, Gathercole & Joanisse, 2009). Despite the greater articulatory demands of multisyllabic forms for producing well coordinated speech gestures, repetition was more accurate for the multisyllabic than single syllable conditions for both of these typical populations.

One difficulty encountered in studies assessing the influence of speech motor output on speech production is that motoric demands are difficult to measure and, hence, to equate across nonword stimulus sets. For example, lists of nonwords designed to be motorically simple and complex will likely differ in other dimensions as well such as numbers of syllables, inclusion of specific phonemes and consonant clusters, and prosodic patterns. In the present study, we use a different tactic by introducing an articulatory perturbation that increases motoric demands. Specifically, we employed a bite block manipulation. Bite blocks have been used previously in the study of lip kinematics in stuttering (Namasivayam, van Lieshout & De Nil, 2008), feedback control in apraxia of speech (Jacks, 2008), and articulatory compensation in children with phonological disorders (Edwards, 1992; Towne, 1994). Bite block compensation requires talkers to reorganize their motor plan for speech production relative to the pattern used normally. In a bite block compensation task, listeners hold material between their molars. The presence of the block requires listeners to use a different set of articulatory movements to produce speech, as jaw movement can no longer be used to facilitate articulatory movements. This compensation occurs rapidly and automatically in normal adult talkers, presumably reflecting their ability to exploit their knowledge of the many-to-one mapping between articulatory maneuvers and their resulting acoustic outcomes. For this reason, tasks involving bite block compensation provide an opportunity to examine the contributions of motor ability, broadly construed, on performance on different production tasks.

In the present study, we employed two lists of nonwords equated for number of phonemes, consonant clusters, syllables, and complexity and compared repetition of these nonwords either in a standard recall task or with a bite block in place. There are two possible ways that this change in motor speech demands may influence nonword repetition: (1) Direct: There may be a direct relationship between increased motoric demands and reduced repetition accuracy. If this were the case, we would expect articulation of specific sounds requiring the greatest motor reorganization to be disproportionately but consistently affected. That is, resulting errors on specific phonemes should occur regardless of length or prosodic complexity. (2) Indirect: Alternatively, the influence of motoric complexity may be realized as an increased processing load in working memory or as an inherent weakness in an already fragile linguistic system. If the bite block manipulation imposes a more general load on the system such as this, we would expect to observe more general effects related to factors such as length or prosodic complexity, and we would expect that the effect may interact with impaired working memory or language.

In order to examine the influence of our motor speech manipulation by itself and in concert with working memory or linguistic deficits, we included typically developing children as well as those with specific difficulties in either working memory or language. All of the children had been identified in our previous study (Archibald & Joanisse, 2009) in which we screened 400 children on a nonword repetition and sentence recall task and then completed

assessments with 52 of the poor and 38 of the good repeaters. The test battery included measures of phonological and visuospatial short-term memory, verbal and visuospatial working memory, language, and nonverbal intelligence. Children were considered to have SLI if they scored in the deficit range on the language test but not on the working memory measures whereas if the opposite was true - if they scored in the deficit range on the working memory measures but not the language test, they were considered to have a Specific Working Memory Impairment (SWMI). A group of children with Mixed working memory and language impairments were identified also. Children with SLI may be expected to have difficulty with the linguistic units of their language. SLI groups have also been found to have more difficulty producing well-organized and stable rhythmic speech motor movements than typically developing groups (Goffman, 1999, 2004). Children with SWMI, on the other hand, do poorly when task demands include both processing and storage across domains. Note that the performance of these children should be similar to typically developing children for storage-only short-term memory tasks but decline when processing loads are added to the task.

The present study compared standard nonword repetition to nonword repetition constrained by the presence of a bite block in four groups of school age children: typically-developing; working memory impaired; language impaired; working memory and language impaired. One purpose was to examine whether motoric perturbation would have a direct impact on nonword repetition in the absence of working memory or language deficits. Poor nonword repetition in the constrained as compared to the standard recall condition in the typically developing group would demonstrate the significance of motor speech demands on nonword repetition. A second aim was to investigate whether increased motor speech demands impact processing load in working memory or are associated with language impairment. Findings that all three of the atypical groups in the present study showed performance decrements in constrained nonword repetition would indicate that motoric demands impact both working memory and linguistic performance. Disadvantages as a result of the motoric manipulation limited to either the working memory- or language- impaired groups would point to a more specific relationship.

Method

Participants

Children in this study had participated in our previous study investigating language and working memory impairments in school age children (Archibald & Joanisse, 2009). We invited 74 individuals to participate including all of the children who had been identified in the previous study as having LI with or without WM impairments ($n = 27$) and all of those with a SWMI ($n = 7$). Additionally, we invited those from the unclassified WM without LI group who had a discrepancy between their standardized language test score and standardized WM score averaged across verbal and visuospatial modalities equivalent to 1 SD unit or 15 points ($n = 6$ out of 18; Note: two eligible children were not invited from this group, one because the child could not be located and the other due to a coding error) and those from the typically developing group who could be located at the same schools as those

in the impaired groups ($n = 34$ out of 39). A total of 59 of these children agreed to participate (29 boys) ranging in age from 6.3 to 10.2 years.

All of the children had completed a battery of standardized tests 4 to 5 months prior to the present study and described in detail in Archibald and Joanisse (2009). Briefly, the *Test of Nonverbal Intelligence-3* (TONI-3; Brown, Sherbenou, Johnsen, 1997) was administered as a measure of general nonverbal cognitive ability. In addition, the f subtests of the *Clinical Evaluation of Language Fundamentals-4* (CELF-4; Semel et al., 2003) were completed as the reference standard for language skills. The core subtests consisted of Concepts and Following Directions, Recalling Sentences, Formulating Sentences, and depending on the age of the child, *Word Knowledge* (under nine years) or *Word Classes* (nine or older). As in our previous study, participants were considered to have a language impairment (LI) if their Composite Language Score (CLS) on the core subtests of the CELF-4 was more than 1 SD below the mean (< 86).

The *Automated Working Memory Assessment* (AWMA; Alloway, 2007) provided a test of working memory. The AWMA includes twelve subtests, three of which target each of phonological short-term memory, visuospatial short-term memory, verbal working memory, and visuospatial working memory. In our previous study, we considered children who scored more than 1 SD below the standardized mean on both the verbal and visuospatial working memory composites to have a working memory impairment (WMI). In order to increase the sample size of this group in the present study, we also included children who scored below 86 on either the verbal or visuospatial working memory composite and whose score averaged across these composites was at least 1 SD lower than their CLS.

Based on our definitions, our sample included typically developing children (no WMI or LI; $n = 28$), children with LI-only (LI but not WMI; $n = 15$), children with WMI only (WMI but not LI; $n = 8$), and children with both LI and WMI (Mixed; $n = 8$). Note that the LI-only group differs from the SLI group in our previous study (Archibald & Joanisse, 2009) in that children with LI in this group may also have had a score below 86 on either verbal or visuospatial working memory but did not meet our other criteria for WMI (i.e., their working memory composite was not 1 SD lower than their CLS). Descriptive statistics for these groups appear in Table 1. In addition to significant deficits for the impaired groups on the tests for which they were defined relative to the typically developing group, the groups with language impairment (LI-only; Mixed) had significantly lower scores on the TONI-3 and phonological short-term memory composite.

Procedure

All participants completed three individual sessions of 30-40 minutes approximately one week apart in a quiet room in their school. The nonword repetition task reported in the present study was completed during the first session.

The nonword repetition task consisted of immediate recall of lists of 15 nonwords presented under two conditions, biomechanically *constrained unconstrained*. The unconstrained repetition task was always completed first and simply involved asking the child to listen to each made-up word and repeat it back immediately. No attention was drawn to the motor

component of this task in any way. For the constrained repetition task, the only difference was that prior to the task the child was asked to place and hold gently with the teeth a small gummi bear candy between the side molars so that the length of the bear aligned with the anterior-posterior plane. The gummi bear served as a bite block, and measured approximately 10 by 20 mm. Note that children were required to hold the gummi bear in place for about one minute to complete the constrained repetition task, and all complied without difficulty. Nonwords were presented auditorily via a digital audio recording of an adult female speaker in fixed random order, and responses were recorded using custom software program written in Visual Basic (Microsoft Corporation, 2003). Item-level scoring was completed online by a trained research assistant who judged each nonword production as correct or incorrect. A total of 10% of the recorded responses were rescored by the first author, and agreement between the two ratings was 95% (range: 93-100%) indicating excellent interrater reliability.

The stimuli were taken from the *Children's Test of Nonword Repetition* (CNRep; Gathercole & Baddeley, 1996), which consists of 40 nonwords divided equally into 2-, 3-, 4- and 5-syllable items with half the items containing consonant clusters. For the present study, two lists were created that would pose equivalent motoric demands. To do this, CNRep items were coded for number of syllables, number of phonemes, number of consonant clusters, and number of biphones that were not consonant-vowel sequences. The codes were summed to give an overall complexity score, from which matched lists of 15 nonwords were created (see Appendix 1). Ten items without a match on these measures were excluded from these lists.

Results

Descriptive statistics for the number of nonwords correctly repeated are presented for both unconstrained and constrained nonword repetition by all four participant groups in Table 2. Only the Mixed group showed any appreciable decline in performance in the constrained condition. A 4 (group) by 2 (movement type: unconstrained or constrained) ANOVA completed on the total items correct score revealed a significant main effect of group, $F(3,55) = 7.374, p < .001, \eta^2_p = 0.29$, due to the lower scores of the LI-only ($p = .039$) and Mixed ($p < .001$) than the typically-developing group. Remaining pairwise comparisons with Bonferroni correction were not significant ($p > .05$). The main effect of movement type $F(1,55) = 3.341, p = .073, \eta^2_p = 0.06$, while the interaction was not significant, $F(3,55) = 1.509, p = .22, \eta^2_p = 0.07$.

It is clear from the preceding results that the biomechanical perturbation of holding a gummi bear between one's molars had a small effect on the data set overall ($\eta^2_p = 0.06$), which may account for the failure to find a reliable interaction between group and movement type. It is reasonable to assume that the motor constraint condition would have a larger effect on the most difficult nonwords overall. Thus, we examined group differences in nonword repetition across conditions for the six nonwords from each set with the highest complexity ratings (12) and having at least three syllables (see Table 2). Numerical scores were lower in the constrained condition for three of the groups when comparing these complex nonwords with

the Mixed and LI-only groups showing substantial reductions and the typically developing group showing only a minimal change.

As in the previous analysis, results of the ANOVA performed on the complex nonword repetition scores revealed a significant main effect of group, $F(3,55) = 8.856, p < .001, \eta^2_p = 0.33$, due to the lower scores of the LI-only ($p = .006$) and Mixed ($p < .001$) than typically-developing groups. Additionally, the main effect of movement type was significant, $F(1,55) = 11.418, p = .001, \eta^2_p = 0.17$, resulting from the poorer performance in the constrained condition overall. The interaction between group and movement type just missed significance, $F(3,55) = 2.659, p = .057, \eta^2_p = 0.13$. Analysis of simple effects revealed a significant disadvantage in the constrained condition for the two groups with language impairment only, the LI-only ($p = .008$) and Mixed ($p = .011$) groups.

In order to further examine whether the biomechanical perturbation was specifically detrimental for children with language rather than working memory impairments, we completed two additional ANOVAs comparing (1) children with (i.e., collapsing the LI-only and Mixed groups) or without (i.e., collapsing the SWMI and typically developing group) a language impairment and (2) children with (i.e., the combined WM-only and Mixed groups) or without (i.e., collapsing the SLI and typically developing group) a working memory impairment. In the first ANOVA comparing children with ($n = 23$) or without ($n = 36$) language impairment, all effects were significant: group, $F(1,57) = 19.784, p < .001, \eta^2_p = 0.26$; movement type, $F(1,57) = 6.185, p < .001, \eta^2_p = 0.22$; and the interaction, $F(1,57) = 6.814, p = .012, \eta^2_p = 0.11$. Analysis of simple effects revealed that while the LI group performed more poorly than the group without language impairment under both repetition conditions, the effect size was greater for the constrained ($d = 1.38$) than the unconstrained condition ($d = 0.78$). As well, only the LI group showed a significant decline in performance on the constrained compared to unconstrained movement conditions ($p < .001$).

For the comparison of children with ($n = 17$) and without ($n = 42$) working memory impairment, the ANOVA yielded significant main effects of group, $F(1,57) = 5.271, p = .025, \eta^2_p = 0.09$, and movement type, $F(1,57) = 10.269, p = .022, \eta^2_p = 0.15$, but the interaction was $p = 0.003$. These results indicate that while both children with language impairment and working memory impairment had lower scores than typically-developing children in nonword repetition, only the performance of those with a language impairment was further impaired in the motor-constrained condition.

In a final set of analyses, we examined the associations between the nonword repetition tasks and standardized language and working memory skills for both the lists of all nonwords and complex nonwords only across the entire data set (Table 3). Significant zero-order correlations were found between all measures. These high correlations occurred due to the wide range of abilities present in this cross-sectional data as reflected by the significant correlations between nonverbal intelligence (but not age) with all remaining measures. The partial correlations controlling for nonverbal intelligence presented in Table 3 better reflect the unique patterns in the data. The composite scores for language, phonological short-term memory, and verbal working memory, themselves highly correlated, were significantly associated with both movement tasks. Visuospatial working memory was correlated with

nonword repetition in the constrained condition for the full set of nonwords, but not for the subset of only the complex nonwords. Visuospatial short-term memory, on the other hand, was not linked to any of the nonword repetition lists. Only the correlations for the complex nonwords and the language and phonological short-term memory measures were significantly different (higher) for constrained than unconstrained repetition, Williams $t(56) > 2.04, p < .05$, both cases (Cohen & Cohen, 1983). Thus, the links between language and phonological short-term memory skills were greater for constrained than unconstrained nonword repetition, whereas an effect of biomechanical constraint was not found for the working memory measures across domains.

Discussion

The present study examined speech motor influences on nonword repetition in groups of children with either language or working memory impairments, both impairments, or typical development. Performance on a biomechanically unconstrained nonword repetition task was compared to repetition under a motoric constraint achieved by placing a gummi bear candy as a bite block between the side molars. The effect of biomechanical constraint was found to be small for the full nonword sets that included both motorically simple and complex nonwords of 2 to 5 syllables. Based on the reasonable assumption that the motoric effect would be larger on motorically complex nonwords, we focused our analyses on the complex nonwords only in an effort to better understand the relationships between, language, working memory, speech motor skills, and nonword repetition. Our findings were clear. Only the children with language impairment regardless of working memory status were found to be significantly more impaired in the motorically constrained nonword repetition task than the typically developing group. Additionally, the positive relationships between both language and phonological short-term memory skills with nonword recall were greater for the constrained than unconstrained repetition conditions. Working memory measures across domains, on the other hand, were not differentially linked to motor condition although the verbally-mediated measures were correlated with all nonword repetition tasks.

The effect of the speech motor perturbation was quite small for most of the children in this study. The presence of the bite block served to disrupt both the extent of articulator movement required and the proprioceptive feedback mechanisms required during recall attempts. However, children with typical development and those with specific working memory impairments were able to adjust their motor commands to accurately recall unfamiliar phoneme sequences. In fact, it was only when the speech sequences were longer and motorically complex themselves that the motor constraint condition had a reliable effect. These findings suggest that the speech motor demands of nonword recall generally play a small role in repetition accuracy.

Nevertheless, the speech motor perturbation did influence nonword repetition in the children with language impairment, who repeated complex phoneme sequences less accurately when their speech articulators were held in an unusual orientation by the presence of a bite block. It seems that these children could not adjust to changes in motor demands and feedback as readily as other children. The findings establish a motoric component to the developmental language impairment of these children and contribute to the growing evidence that children

with SLI have less mature neurocognitive systems supporting oral motor control (Goffman, 1999) and produce less organized and stable speech movements (Goffman, 2004). It is clear from these findings that speech motor and linguistic skills are linked in ways that are not yet fully understood but warrant further investigation.

The present findings replicate many previous reports of nonword repetition deficits for children with language impairments (e.g., Gray, 2003; Conti-Ramsden et al., 2001). The current results can speak less clearly, however, to the question of whether nonword repetition is primarily a short-term memory task or a language task. Phonological short-term memory and the composite language score were very closely related in the present study and showed very similar associations with the nonword repetition tasks. Nevertheless, there were some indications that phonological short-term memory may be particularly important to recall accuracy: The correlations with nonword repetition were numerically larger for phonological short-term memory than language, and the latter did not show a significant link to unconstrained repetition of complex nonwords. It must be acknowledged however that the close relationship between language and phonological short-term memory skills in children with language impairment in the present study may have been influenced by the manner in which the children were initially identified. As described in detail by Archibald and Joanisse (2009), the children were selected based on their performance on a screening measure of nonword repetition and sentence recall that may have resulted in a higher co-occurrence of phonological short-term memory and language deficits than in other SLI groups.

Nonword repetition in children with specific working memory impairments in the present study did not differ from that of typically developing children. Although children with working memory with or without language impairments did receive lower scores, the size of this pooled group was doubled by the addition of those with a working memory plus language impairment making it likely that these added individuals with language (and phonological short-term memory) impairment drove the group effect. These findings are consistent with suggestions that nonword repetition poses storage-only demands tapped by measures of short-term memory rather than storage plus processing as measured by working memory tasks (Gathercole & Baddeley, 1993). Our question was whether the added load of adjusting motor speech mechanics may confer added demands for processing. The answer was generally, no. While there were some indications in the data for the working memory measures across domains to be more strongly related to the motorically constrained repetition performance, these trends were not reliable. It may be too that any modest relationship here is mediated by another factor such as vigilance. It should be noted that one possible limitation of the present study was that the motor perturbation employed was too small to impact the speech production abilities of the typically developing and SWMI groups leading to an underestimation of the overall and direct effect of motor demands on nonword repetition. While further would be needed to examine this possibility, the differential performance pattern across groups in the present study remain important.

Conclusions

Nonword repetition performance has long been considered to tap a variety of cognitive processes including short-term memory, linguistic knowledge, motor output, etc. (Coady &

Evans, 2008). The present study focused on the influence of speech motor skill on nonword repetition in children with language impairment, working memory impairment, both language and working memory impairment, or typical development. Only the children with language impairment with or without working memory impairment had a significant detriment in performance when holding a bite block between the side molars. These children were less able than the typically developing children to make the necessary motor adjustments to this perturbation. These findings add to the growing evidence that there is a motoric component to developmental language disorders. The results also suggest that generally speaking the role of speech motor skill in nonword repetition is relatively modest.

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Table 1

Descriptive statistics for standardized tests ($M=100$, $SD=15$) of language, nonverbal intelligence, short-term and working memory for all groups

Area tested		Mixed ($n=8$)	LI-only ($n=15$)	WMI only ($n=8$)	No deficits ($n=28$)
Age in years - M (SD)		8.9 (0.85)	8.7 (0.9)	8.3 (1.3)	8.4 (1.1)
Number males		4	7	3	15
TONI-3 ^a	M	91.13 ^a	90.07 ^b	103.63	111.92 ^{ab}
	SD	7.02	12.09	11.96	16.07
CELF-4 ^a	M	70.50 ^a	74.27 ^{bc}	103.00 ^c	105.44 ^{ab}
	SD	10.60	10.18	10.81	10.89
Phonological STM ^{ab}	M	79.63 ^a	82.67 ^b	95.50	106.44 ^{ab}
	SD	9.91	16.46	10.50	16.07
Verbal WM ^{ab}	M	71.38 ^a	89.27 ^b	82.50 ^c	110.28 ^{abc}
	SD	9.67	16.15	11.61	13.65
Visuospatial STM ^{ab}	M	77.87	96.87	102.50	107.60
	SD	14.77	19.18	15.86	26.79
Visuospatial WM ^{ab}	M	73.50 ^a	98.53	76.88 ^b	111.32 ^{ab}
	SD	10.17	10.33	14.17	16.44

Note: STM – Short-term memory; WM – Working memory; Mixed = WM and language impairment; like superscripts in the same row indicate significantly different pairs, $p < .01$.

Table 2

Mean number of items correctly repeated (SD) at short, long, and all nonword lengths for each task and participant group

Condition	Nonwords		Participant Group							
	No.	Nonwords	Mixed (n = 8)		LI-only (n = 15)		WMI only (n = 8)		Typical (n = 28)	
Complexity			M	SD	M	SD	M	SD	M	SD
Typical	All	15	9.38	2.07	10.47	2.75	10.75	3.32	12.36	1.83
	Complex	6	3.00	1.20	3.73	1.44	3.75	1.67	4.75	1.21
Constrained	All	15	7.63	2.72	10.20	2.37	10.75	3.45	12.21	1.97
	Complex	6	1.75	1.04	2.80	1.52	3.87	1.46	4.43	1.26

Table 3

Zero-order (upper right) and partial (lower left) correlations controlling for nonverbal intelligence between standardized test scores and nonword repetition performance for each motoric condition

	All nonwords		Complex nonwords		Lang	PSTM	VWM	VSP STM	VSP WM
	Set 1	Set 2	Set 1	Set 2					
Age (mths)	.19	.10	.23	.11	-.02	.01	.15	.19	.03
Nonverbal Intelligence (NI) ^a	.40**	.39**	.39	.46**	.62**	.48**	.51**	.36**	.49**
All nonwords: Typical (Set 1)		.72**	.85**	.81**	.46**	.54**	.53**	.13	.32*
All nonwords: Constrained (Set 2)	.68**		.67**	.61**	.51**	.54**	.58**	.2	.42**
Complex nonwords: Set 1	.82**	.54**		.68**	.43**	.53**	.51**	.16	.28*
Complex nonwords: Set 2	.60**	.77**	.62**		.63**	.70**	.64**	.26*	.39**
Language ^b	.29*	.37**	.26	.50**		.66**	.57**	.40**	.46**
Phonological STM ^c	.44**	.44**	.42**	.61**	.52**		.63**	.20	.43**
Verbal WM ^c	.40**	.48**	.40**	.53**	.38**	.51**		.41**	.72**
Visuospatial STM ^c	.01	.07	.02	.16	.25	.03	.28*		.49**
Visuospatial WM ^c	.15	.29*	.10	.22	.16	.25	.63**	.38**	

Note:

^aTest of Nonverbal Intelligence

^bComposite Language Score

^cAutomated Working Memory Assessment

* $p < .05$

** $p < .01$