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The Effects of Phonological Short Term Memory on Lexical and Grammatical Production Skills in Persian Children with Developmental Language Disorder

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Abstract
The deficit in verbal working memory (vWM) skills has been frequently reported in children with developmental language disorder (DLD) and may contribute to their problems in language. This study aimed to compare the phonological short-term memory (pSTM) and linguistic skills between Persian-speaking children with DLD and typical language development (TLD) to explore the role that pSTM plays in lexical and grammatical problems of children with DLD. This study included 32 Persian-speaking children who were divided into two groups of DLD (n = 16) and TLD (n = 16) within the age range from 6 to 8 years. The Persian non-word repetition test was employed as the measure of pSTM. Lexical and grammatical indices were extracted from narrative generations. Independent-samples *t* test was used to analyze the group-related differences in vWM, lexical, and grammatical skills. Moreover, the one-way ANCOVA analysis by controlling for NWR was utilized as the covariate to investigate the effects of vWM on linguistic performances. According to the results, the children with DLD scored significantly lower on NWR task and all lexical and grammatical measures, compared to TLD children ($P < 0.01$, $d > 1$). The group-related differences disappeared after controlling for NWR ($P > 0.05$). The results show that Persian-speaking children with DLD experience significant difficulties in pSTM skills, which affect their lexical and grammatical performances.

Keywords Developmental language disorder (DLD) · Lexical performance · Morpho-syntax · Non-word repetition · Verbal working memory

Introduction

Language is a well-organized device for human communication and thinking. The acquisition of language by young children is an automatic process and occurs easily through interaction with the environment. However, not all children develop it effortlessly. Developmental language disorder (DLD) refers to children with apparent problems in spoken

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Extended author information available on the last page of the article language and communication with unknown biomedical or neurodevelopmental causes whose problems persist beyond 5 years of age (Norbury 2017). Until recently, this disorder has been mostly known as specific language impairment or primary language impairment by researchers and clinicians. However, the term DLD was suggested and agreed by the international CATALISE consortium of clinicians, educators, parents, and researchers (Bishop et al. 2016).

The DLD affects both comprehension and production modalities in different aspects of language and results in apparent language difficulties, such as obvious morpho-syntactic errors, limited vocabulary, errors in the production of sounds, as well as difficulties in retrieving the words and understanding sentences (Leonard et al. 2007; Norbury 2017). This disorder is prevalent and affects two children in each classroom on average (Norbury 2017). Evidence obtained from more than two decades of the studies on children with DLD indicates that the problem in linguistic knowledge is more obvious; however, it is not the only problem in this group of children. Despite normal intelligence, children with DLD show substantial difficulties in some cognitive domains, specifically in verbal working memory (vWM) (Leonard et al. 2007).

The WM is a capacity-limited storage system under attention control that is likely underlies language learning, decision making, adherence to instructions, reading, and problem solving (Baddeley 2003). Baddeley's multicomponent model introduces WM as a multi-dimensional system that includes a central attention-control component (i.e., central executive) and two capacity-limited specialized components for storage (i.e., the phonological loop and the visuospatial sketchpad). The phonological loop, which is also called the phonological short-term memory (pSTM), is responsible for the temporary storage of phonological information and preserve them via rehearsal process. Visuospatial sketchpad has the same responsibility for visual materials (Baddeley 2003). The episodic buffer, the fourth and last added component to the model, allows information to be integrated within the WM system and links them to the stored knowledge in long-term memory (Baddeley 2000).

The function of the phonological loop is often evaluated through verbal retrieval tasks, such as non-word repetition or serial retrieval of a list of non-related digits/letters/words (Haresabadi and Shirazi 2015; Dehn 2011). It is believed that non-word repetition provides the most popular and accurate estimation of verbal-STM performance due to the less dependency on linguistic stimuli (Estes et al. 2007). Tasks, such as backward digit recall or backward word span, which require the simultaneous storage and processing of auditory stimuli, are used in children to assess verbal working memory span (i.e., the coupled performance of phonological loop and central executive) (Dehn 2011).

It is thought that WM plays an essential role in language learning and functioning (Adams and Gathercole 1995; Baddeley et al. 1988). Some researchers have found a strong correlation between the pSTM span and the size of the vocabulary of preschool children and suggested that pSTM supported vocabulary learning at least in the early years of language development (Gathercole 2006; Gathercole et al. 1992). Ramachandra et al. (2011) have proposed that phonological working memory is involved in forming stable phonological representations in the mental lexicon through the storage and processing of phonological aspects of new lexical items.

Apart from the connection between vocabulary and WM, some researchers argue that WM could play an important role in learning of the grammatical forms and syntactic structures (Baddeley et al. 1998; Duinmeijer et al. 2012; Marini et al. 2014).

Tomasello (2000) argues that language acquisition is nothing other than simple imitative learning from adult utterances; these utterances are represented in memory and then the words, rules, morpho-syntactic categories, and structures that are discovered through a chunking mechanism. Presumably, WM plays a role as an intermediary mechanism in this analytical process (Archibald 2017; Montgomery et al. 2010). Andrade and Baddeley (2011) suggested that the phonological loop contributes to the acquisition of grammar by the impact on vocabulary learning. The results of a study carried out by Blake et al. (1994) indicated that the pSTM span can predict the mean length of utterances (MLU) of preschool children even better than the chronological or mental age. Adams and Gathercole (1995) also proposed that pSTM span could be served as the predictor of the quality and quantity of the spontaneous speech of 3-year-old children. Their results revealed that children with higher pSTM produce longer sentences, which simultaneously contain more expanded syntactic structures and lexical variability. The results of studies conducted by Sansavini et al. (2007), as well as Williams and Lovatt (2003) are consistent with these findings.

As noted previously, deficits in pSTM have been frequently reported in children with DLD (Alt 2011; Montgomery 2006). Many studies in recent years have revealed that the performances of children with DLD in non-word repetition lag significantly behind their age-matched and even their younger language-matched peers (Gathercole and Baddeley 1990). Bishop et al. (1996) specified that non-word repetition could be used as a sensitive identifier for DLD, even when the problems of children in different language domains are resolved or compensated. Hill et al. (2015) also suggested that the presence of significant and persistent deficits in non-word repetition in the group of children with DLD is the primary difference between these children and those with autism plus language impairment. In addition to apparent pSTM deficits, significant weaknesses in controller mechanisms within the WM system have also been stressed in the group of children with DLD (Archibald and Gathercole 2006, 2007; Im-Bolter et al. 2006).

Notable difficulties of children with DLD in non-word repetition and other WM related tasks have played a significant role in the development of theories of DLD. Gathercole and Baddeley's "phonological storage deficit hypothesis" argued that children's difficulty in storing the entering phonological information was likely to be the cause of lexical and grammatical defects of these children (Baddeley 2003; Baddeley et al. 1998). The results of a study carried out by Duinmeijer et al. (2012) showed that the individual differences of children with DLD in the tasks of pSTM, such as digit recall, were in positive correlation with MLU and grammar learning capacity. Dodwell and Bavin (2008) showed that the linguistic performances of children with DLD in narrative production were linked to their scores on a vWM test. These authors suggested that the efficiency of the "auditory processing system" of children with DLD might not be as well as their typical language development (TLD) peers. Vugs et al. (2017) found that verbal working memory proficiencies at age four could strongly predict language skills at age seven. There were no differences in the developmental influences of WM on the language between language-impaired and normally developing children. Interestingly, there were few children with DLD and normal levels of vWM, and it was observed that these children produced longer utterances and obtained higher scores in tests assessing linguistic skills (Archibald 2017; Botting and Conti-Ramsden 2001).

Furthermore, in children with DLD plus WM impairment, it was specified that vocabulary defects were also highly inherited (Peterson et al. 2013). Given the importance of pSTM for language functioning in literature, the present study explored how accurate Persian-speaking children with DLD are in non-word repetition test, compared to children with TLD, and what the impact of their non-word repetition skills is on their lexical and grammatical performances. Non-word repetition task was chosen to evaluate the pSTM skills due to its more sensitivity in evaluating the phonological loop function than other measures, such as the digit span (Baddeley et al. 1998). In non-word repetition, the participants are asked to accurately repeat the unfamiliar spoken forms; therefore, there are no lexical supports for repetition of these unexperienced sound patterns, and the children must heavily rely on phonological loop as a mean, which provides a temporary representation of non-words (Gathercole and Baddeley 1990).

Several studies suggested that children with DLD performed worse than their TLD peers in non-word repetition, and this task could be served as an accurate and less culturally biased measure to identify the children with DLD (Bishop et al. 1996; Campbell et al. 1997). However, the results of at least one study conducted by Stokes et al. (2006) showed that Cantonese preschool children with DLD did not score significantly lower than their age-matched peers on non-word repetition tasks. These researchers argued that there might be no limitations in working memory skills of Cantonese-speaking children with DLD although other important reasons may also exist (Maleki Shahmahmood et al. 2016). Apart from the reason, such results confirm the necessity of conducting studies in different languages and cultures. The results of a study conducted by Kazemi and Saeednia (2017) on preschool Persian-speaking children with DLD and TLD showed significant differences between the two groups in terms of non-word repetition. However, Ahadi and Mokhlesin (2016) found no significant correlation between the non-word repetition and language scores of typically developing Persian preschoolers. Such contradictory findings emphasize the need for further studies.

This study aimed to compare the morpho-syntactic, lexical, and pSTM abilities of 6–8-year-old Persian children suffering from DLD with their typically developing peers. Moreover, it was attempted to explore the role that could be potentially played by pSTM in grammatical and lexical processing of children with DLD. Our initial hypothesis was that the levels of pSTM skills, which assessed in terms of non-word repetition, could affect the grammatical and lexical language performances of children with DLD. Therefore, in line with the hypothesis expressed by Marini et al. (2014), it was assumed that the significant differences between the groups of Persian-speaking children with DLD and TLD regarding grammatical and lexical measures affected by pSTM skills would disappear when controlling non-word repetition in the statistical analyses. Storytelling task was used to provide a clear picture of the grammatical and lexical performances of children. It is proposed that storytelling is the most comprehensive way of linguistic assessment since it elicits a wide range of linguistic capacities (Duinmeijer et al. 2012). Moreover, it is sensitive to the lexical and grammatical defects of children with DLD, even when they can overcome their linguistic problems in the test situation and even up to adulthood (Wetherell et al. 2007a, b).

Materials and Methods

Participants

In total, 32 monolingual Persian-speaking children participated in this study and were divided into two groups of DLD (M = 6;6, SD = 5 month) and TLD (M = 6;6, SD = 6 month). It is worth mentioning that the two groups were matched in terms of number (n = 16), gender (11 boys and 5 girls), and age. All the participants were monolingual Persian-speakers.

The participants in the DLD group were all children who referred to the special-education services in schools, as well as private or governmental speech therapy clinics in Mashhad, Iran, for 6 months. The inclusion criteria were: (1) no signs of known biomedical conditions that can cause language impairment, such as autism spectrum disorder, intellectual disability, sensory disorders, brain damage or seizure according to the parental reports and the child's health dossier, (2) passing a hearing screening at 20 dbHL at 500, 1000, 2000, and 4000 Hz, (3) successful performance in an oral-motor functioning assessment with no signs of dysarthria, (4) IQ scores within the normal limits (above 70) in Persian revised version of Wechsler intelligence scale for children (WISC-R) (Shahim 2008) and no sign of limitation in adaptive behaviors, and (5) performing at least 1.5 standard deviations below the mean (mean = 71.3, SD = 5.4) in the Persian version of TOLD-P:3 (Hassanzade and Minayi 2010).

The clinical judgment of the examiner, as an experienced speech and language pathologist (SLP) in the domain of language disorders, verified the diagnosis of DLD. Children with TLD were selected from kindergartens and elementary schools in Mashhad, Iran. Each child was individually matched with one child in the DLD group based on three criteria, including the chronological age (± 1 month), gender, and socio-economic status (based on parental education and the place of residence). None of these children had a history of speech or language problems, intellectual deficits, neurological or psychiatric illnesses, and sensory problems in hearing or vision according to the teachers' reports and the school records. Informed consent was obtained from the parents of all children at the time of participation.

Materials and Procedures

Participants were tested individually in a quiet room at a speech therapy clinic (for DLD group) or at a quiet class at schools (for the TLD group) by the same qualified SLP. The administration of all language and memory tasks, including narrative, one lexical probe, one morpho-syntactic probe, and non-word repetition, required two 45-min sessions for every participant.

Narrative analysis was used as the main tool to assess the participants' lexical and grammatical skills. Moreover, two additional linguistic probes were also administered to complete and confirm the results of narrative analysis. The oral vocabulary subtest of the Persian version of TOLD-p:3 (Hassanzade and Minayi 2010) and Photographic expressive Persian grammar test (PEGT) (Haresabadi et al. 2016) were used as lexical and morpho-syntactic indices, respectively. Furthermore, the non-word repetition test for the Persian children (Soleymani et al. 2014) was employed to measure the WM in this study.

Linguistic Assessments

Narrative Elicitation Task

Farsi Narrative Norms Instrument (Soleymani et al. 2016) was utilized to extract storytelling samples. Children's language samples were recorded by a Phillips-VTR-7100 digital voice recorder during the storytelling and were orthographically transcribed. Decisions about the utterance segmentation, morphemes, and word roots were made based on the Persian-adapted conventions of systematic analysis of language transcripts (SALT) called Persian transcription conventions protocol (PTCP) (Kazemi 2013). All complete and intelligible utterances were included in calculating the grammatical and lexical measures. The transcriber rechecked all transcribed and coded files. Intra-rater reliability was also determined for a random set of 20% of recorded language samples transcribed by a trained undergraduate student of speech therapy. Pearson's test of association showed an overall correlation above 0.9 (range 0.83–1.0) between the two transcribers. Moreover, within-sentence analysis of narrative samples carried out by focusing on lexical-semantic and grammatical aspects of language. Lexical indices derived from narrative samples were speech rate, percent of semantic errors, type-token ratio (TTR), and semantic enhancement index (SEI). Grammatical skills of participants were assessed in terms of MLU, percentage of grammatical utterances (% GU), syntax complexity, and morpho-syntactic organization (Table 1).

Photographic Expressive Persian Grammar Test (PEGT)

This grammar production test is a fast- and easy to administer tool that comprises 40 image items and designed to evaluate the production of important morph-syntactic structures of Persian in 4–6-year-old children (Haresabadi et al. 2016). This test assesses the most basic and critical Persian syntactic structures that are extremely difficult to be learned by children with DLD even in older ages. Due to the lack of formal tests of grammar in Persian, this test was applied as an available valid task to evaluate the participants' competences in morpho-syntactic production alongside the storytelling task.

Oral Vocabulary Subtest of TOLD

This scale is the semantic sub-test of the Persian version of TOLD-p: 3 (Hassanzade and Minayi 2010), which measures participants' ability to produce verbal definitions for the words. This task encompasses 28 stimuli and each stimulus includes a common Persian word that is introduced to the child verbally and must be described accurately. This subtest of TOLD was applied, and its standard score was calculated for every participant to evaluate the participants' competences in lexical production along with the story generation task.

Assessment of Working Memory

The Persian non-word repetition (NWR) task was used to examine the verbal working memory skills and the performance of the phonological loop sub-component of WM (Soleymani et al. 2014). The Persian NWR consists of two counterpart checklists, each of which contains 25 one- to- four syllables non-words. To maintain the same test conditions for all participants, a single checklist was used for assessment. All the non-words were audio-recorded on DVD. The children's responses were scored both online (while the task was administered) and offline using the child's audio-recorded voice. A trained bachelor student of speech and language pathology computed the reliability check for 20% of the children's recorded data. The original scoring was used in case of disagreement between the raters due to the low intelligibility of the recorded voice. Inter-rater reliability was obtained above 93% (range 90–100%).

Table 1 Lexical and grammatical production indices extracted from narrative samples

	Index	Definition	Calculation method
Lexical production indices	Speech rate	An indicator of the child's ability to quickly select lexical items while generating a story measured in terms of words per minute (Marini et al. 2014)	(Total number of words/total times in sec) × 60
	Percent of Semantic errors	This index points to the percent of words that are substituted with semantically related but inappropriate words (Marini et al. 2020)	(Total number of the semantically inappropriate words in the language sample/total number of words) × 100
	TTR	An indicator of the degree of lexical variation (Owen and Leonard 2002)	Total number of different words in the language sample/total number of words
	SEI	An index that gives an overall measure of participants' use of internal state language (Gagarina et al. 2012; Norbury et al. 2014)	(Total number of adverbs + adjectives + internal state words β + intentional utterances € + character speeches £ − total number of semantic errors)/total number of utterances
Grammatical indices	MLU	The average number of words per utterance that measures morpho-syntactic development in children (Marini et al. 2014)	Total numbers of words/total numbers of utterances
	%GU	A syntactic index that reflects the child's ability to produce well-formed grammatical utterances§ of language (Marini et al. 2014)	(Total number of well-formed grammatical utterances produced within the language sample/total number of utterances) × 100
	Syntax complexity	A syntactic index that indicates the child's ability to produce complex sentences or phrases of language (Norbury et al. 2014)	(Total number of complex utterances γ + total number of noun elaboration phrases λ)/total number of utterances
	Morpho-syntactic organization	An index that reflects the percentage of the grammatical errors, including substitution errors (substitution of function words or bound morphemes) and omission of function words in language sample (Marini et al. 2008, 2020)	(Total number of omission of function words/total number of produced utterances) × 100 + (total number of free or bound morphemes substitution errors/total number of words) × 100

β: words which typically express a feeling (e.g. happy, bored), knowledge, opinion, plan, belief, or dream (e.g., decide, interest, want). €: utterances that convey the planning of one of the characters of the story (e.g., plan, let, tell, look for) or his/her impact on another character's performances (e.g., paying attention, making fun of, hiding). £: everything told by one of the characters of the story and could be placed in quotation marks. §: An utterance was measured as grammatical if all the obligatory arguments of the verb had been correctly inserted, and there were no omissions or substitutions of free or bound morphemes. γ: all utterances which consist of a complete independent clause and one or more dependent clauses connected with subordinating conjunctions. λ: utterances that are comprising more than two modifiers before the noun or relative/gerund clauses following the noun

Analysis

The data were analysed in R software. Regarding the normal distribution of the data for all variables (which was identified by drawing the Q–Q plots in R software), a series of independent-samples t-tests were used to analyze the group-related differences on the measures evaluating WM, as well as lexical and grammatical production. To control the family-wise error rate, the Bonferroni correction was utilized for multiple comparisons. A p-value less than 0.01 (0.05/5 dependent variables) was considered statistically significant for lexical and grammatical indices after Bonferroni correction.

The differences in performance between the two groups were transformed into effect size that measured in terms of Cohen's d, computed as the difference between the scores of the TLD and DLD groups divided by the pooled standard deviation for both groups. It defines the magnitude of the findings and could be interpreted in terms of standard deviation units (Durlak 2009). For instance, $d=1$ indicates that typically developing children performed one SD better than children with DLD, and $d=0.8$ demonstrates a generally accepted minimum level of power and desirability of the higher powers (Durlak 2009).

The test of analysis of covariance (ANCOVA) by controlling the scores on the Persian NWR test as the covariate factor was used to test the effects of pSTM on linguistic performances. It was assumed that there were significant differences between the NWR scores of the two groups, which can be the basis for observed differences in language performance. The prerequisite assumptions for applying ANCOVA and specifically the homogeneity of slopes were also examined in this study. It is worth mentioning that ANCOVA is not appropriate to compare the mean values if the significance level of covariate × factor interaction is less than 0.05.

Results

Table 2 tabulates the descriptive statistics and statistical analysis of both groups in terms of language and memory skills.

As shown, there are significant differences between the performances of DLD and TLD groups in all indices that measure memory ($P<0.001$), lexical skills ($P<0.01$), and grammar production ($P<0.01$). Based on Durlak (2009), all effect sizes are large enough. In Tables 3 and 4, p2 column represents the group-related differences in lexical and grammatical indices, respectively, after controlling for NWR. For better comparisons, a column with the heading p1 is also included that represents the p values before covariation (t-test). The significant levels of covariate × factor interaction are also reported.

Tables 3 and 4 show that $P_{interaction}$ is above 0.05 for all lexical and grammatical variables and confirm the homogeneity of the slopes. According to Table 3, although the group-related differences are significant for all lexical indices before covariation (t-tests), they are no longer significant for all lexical production indices after controlling for NWR (ANCOVA). Similarly, Table 4 indicates that after carrying out the ANCOVA analysis, the group-related differences are not significant for four of the grammar production indices, including MLU, syntax complexity, morpho-syntactic organization, and the scores of the PEGT. However, among grammatical indices, the significant group-related difference is survived for % GU.

Table 2 Lexical measurement, grammatical indices, and non-word repetition in children with DLD and TLD

		DLD (n = 16) Mean (SD)	TLD (n = 16) Mean (SD)	t-value	df	P	d_{cohen}
pSTM	NWR	10.26 (5)	24.4 (0.91)	−10.75	30	0.000*	3.92
Language							
Lexical indices	Speech rate	30.15 (21.6)	68.9(17.02)	−5.45	30	0.000*	1.99
	Semantic errors	2.53 (1.55)	0.25 (0.13)	2.47	30	0.002*	2.07
	TTR	0.16 (0.08)	0.25 (0.06)	−3.37	30	0.002*	1.23
	SEI	0.12 (0.11)	0.41 (0.2)	−3.8	30	0.001*	1.38
	Oral vocabulary (standard score)	7.08 (0.86)	12.9 (1.05)	−6.27	30	0.000*	1.12
Grammatical indices	PHEPGT	11.46 (8.14)	35 (7.5)	−8.21	30	0.000*	2.99
	MLU	3.67 (0.97)	6.07 (1.06)	−6.41	30	0.000*	2.34
	%Gu	31.93 (12.8)	89.1 (5.98)	−15.5	30	0.000*	5.68
	Syntax complexity	10.3 (5.53)	21.7 (8.45)	−3.1	30	0.004*	1.13
	Morpho-syntactic organization (errors)	9.21(11.35)	0.61 (0.53)	5.98	30	0.000*	2.18

*$p < 0.01$

Table 3 Group-related differences in lexical indices before and after covariation

	p_1	d_{cohen}	ANCOVA	
			$p_{interaction}$	p_2
Speech rate	0.000*	1.99	0.43	0.28
Semantic error	0.002*	2.07	0.39	0.06
TTR	0.002*	1.23	0.34	0.69
SEI	0.001*	1.38	0.72	0.41
Oral vocabulary	0.000*	1.12	0.34	0.26

*Significant group-related differences; p_1 reports the between-groups significance level before covariation (t-test); $p_{interaction}$ indicates the significance level for covariate × factor interaction for checking the homogeneity of slopes assumption; p_2 shows the p value after controlling for NWR as covariate

Table 4 Group-related differences in grammatical indices before and after covariation

	P_1	d_{cohen}	ANCOVA	
			$p_{interaction}$	P_2
PHEPGT	0.000*	2.99	0.12	0.46
MLU	0.000*	2.34	0.20	0.66
%GU	0.000*	5.68	0.62	0.000^+
Syntax complexity	0.004*	1.13	0.61	0.13
Morho-syntactic organization (errors)	0.000*	−2.18	0.72	0.4

p_1 reports the first between-groups significance level; $p_{interaction}$ indicates the significance level for covariate × factor interaction for checking the homogeneity of slopes assumption; p_2 shows the p value after controlling for NWR as the covariate. *: significant group-related differences; $^+$: significant group differences after controlling for NWR; PHEPGT = Photographic expressive Persian grammar test

Discussion

This study aimed to examine the association among morphosyntactic, lexical, and pSTM skills in a group of 6–8-year-old Persian children with and without DLD. In the first step, the lexical, grammatical, and pSTM skills of these two groups of children were compared. Subsequently, a comparison was made between the lexical and grammatical variables while controlling the effects of pSTM on linguistic performances.

It was expected that Persian-speaking children with DLD fall significantly behind their TLD peers on lexical and grammatical measures. The results verified this assumption and revealed that before controlling for NWR, children with DLD demonstrated notable problems in the lexical and grammatical measures, compared to their TLD peers. In comparison with TLD children, the language samples produced by participants with DLD were characterized by lower MLU, shorter and simpler sentences, higher incidence of semantic and grammatical errors, and reduced amounts of diversity and informativeness of lexical items. These results are in line with the findings of the previously conducted studies on children speaking different languages, such as Persian, English, Italian, and Dutch (Duinmeijer et al. 2012; Ghayoumi-Anaraki et al. 2018; Kazemi et al. 2015; Maleki Shahmahmood et al.

2011; Marini et al. 2008, 2014). Moreover, as expected, significant differences were found between the mean scores of children with DLD and TLD in terms of PEGT and the mean standard scores in the oral vocabulary subtest of TOLD ($P < 0.01$).

Alongside the notable lexical and grammatical problems, there was a significant difference between the performances of children with DLD and TLD regarding non-word repetition ($P < 0.01$, $d = 3.92$) that suggested a substantial impairment in WM, specifically pSTM skills in Persian children with DLD. Kazemi and Saeednia (2017) have proposed NWR as a potential identifier for Persian-speaking children with DLD in their study.

Previous studies on different languages indicated that children's ability to repeat non-words or a list of digits or words are significantly correlated with their lexical and grammatical development. Moreover, it was proposed that pSTM played a substantial role in language learning and functioning in preschool years (Archibald 2017; Baddeley et al. 1998; Gathercole et al. 1992; Maleki Shahmahmood et al. 2018). It is assumed that WM deficiencies can limit the amount of language information, which can be dealt with and also can reduce the efficacy of encoding and storing the new information (Kronenberger et al. 2011). Furthermore, it is hypothesized that poor repetition of non-words remains relatively stable across development in children with DLD even when problems with linguistic domains are resolved or disappeared (Bishop et al. 1996).

For as much as the language performances of children with DLD might be affected by the levels of pSTM skills, it is assumed that group-related differences in language measures would be disappeared if non-word repetition is controlled. The results provided such evidence and verified that WM skills have a substantial impact on children's lexical and grammatical performances. After controlling the non-word repetition, between-groups differences were disappeared in all lexical and grammatical indices ($P > 0.05$), except for the percentage of grammatical utterances ($P < 0.001$) (Tables 3 and 4). One possible explanation for this finding could be that children's ability to produce grammatically well-formed sentences during the storytelling is more influenced by other factors, such as the ability to apply learned grammatical rules when trying to create longer utterances or a coherent story. This result is compatible with the findings of a study conducted by Marini et al. (2014) in which they investigated the effects of vWM on macro- and micro-linguistic performances of 7–11-year-old Italian-speaking children with DLD.

Among measured grammatical indices in their study, the only measure that was not meaningfully affected by vWM was the percentage of grammatical utterances, whereas other grammatical measures, including MLU, sentence completion, and percent of grammatical errors were significantly affected. Authors proposed that this awkward finding eventually resulted from different factors, such as macro-linguistic processing capacities, which are strongly correlated with micro-linguistic aspects of language processing and might affect the production of well-formed complete sentences in storytelling tasks. Although the results of a study performed by Marini et al. suggested the significant effect of vWM on grammatical skills, this effect was not supported for lexical processing. They claimed that these findings support the theories that suggested the impact of pSTM on learning the new lexical items weakened at older ages (Marini et al. 2014).

Gathercole et al. (1994) assumed that the performance in non-word repetition in preschool children was supported by pSTM and later after approximately age 5 was supplemented by lexical representations from long-term stores. However, as mentioned earlier, our results show that pSTM affects the speed of retrieval of lexical items, lexical variability, and the rate of occurrence of semantic errors in the narrative productions of 6–8-year-old children with DLD and confirm that WM plays an essential role in lexical production skills.

Association between pSTM capacity and the ability to store and learn the novel phonological forms has been found in previous studies (Archibald 2017; Baddeley et al. 1998; Gathercole et al. 1992). Furthermore, it has been claimed that pSTM acts as a basis for rule learning (Dodwell and Bavin 2008; Duinmeijer et al. 2012; Maleki Shahmahmood et al. 2018; Marini et al. 2014; Vugs et al. 2017; Williams and Lovatt 2003). Our results that are consistent with the findings of previous studies suggest that language and cognition are interacting developmentally. Unlike our results, the result of a study carried out by Ahadi and Mokhlesin (2016) (the only study investigated the interconnection between language and pSTM [NWR and forward digit span] in Persian-speaking TLD children) did not support the straight and meaningful association between NWR skills and language performances. However, they found positive statistical correlations between language proficiencies and digit span scores. The observed contradictions could be due to the nature of the used NWR task. Different non-word repetition tasks might differ in structural features, such as non-word length, word-likeness, or articulatory complexity, which could affect the proficiency of the children's performance (Estes et al. 2007).

The non-word repetition task in a study carried out by Ahadi and Mokhlesin (2016) consisted of 30 non-words, including 10 items, which lengthened between one to three syllables. However, the number of syllables varies from one to four in the items of the Persian NWR test, which has been used in our study. It is suggested that children with DLD show significant deficits in the repetition of longer non-words (with more than two syllables) while they have no significant problem in the repetition of shorter non-words with just one- or two-syllables (Bishop et al. 1996; Gathercole and Baddeley 1990). Weak performances of children with DLD at repeating longer non-words can confirm the underlying role of WM in language development. Gathercole and Baddeley (1990) argued that if the repetition deficit is secondary to the low storage capacity of the phonological loop, it is expected that children with DLD experience significant difficulties at repeating longer sequences. This is exactly what is seen in this group of children (children repeat shorter non-words more accurately than longer ones). Furthermore, in children with DLD, the reduced phonological short-term storage resources lead to failures in the repetition of longer non-words to a greater extent, compared to TLD children (Estes et al. 2007).

As the final remark, it is noteworthy to mention the limitations of this study. One possible limitation is that no measure was included to investigate the central controller mechanism in WM. Recent studies indicated the deficits in the central executive sub-component of WM in children with DLD (Archibald and Gathercole 2006; Soleymani et al. 2014; Vugs et al. 2014). This sub-component is responsible for maintaining attention and coordinating the flow of information in the WM system. Although the phonological loop, as a temporary storage place for verbal information, typically has been considered as a basis for language learning and functioning (Baddeley 2003; Baddeley et al. 1988, 1998), it is necessary to specify how language is related to the other sub-components of WM, specifically central executive. Therefore, for future studies, it is suggested to examine the relationship between language and WM skills by those types of WM tasks which let us surveying the counter-interaction of storage and processing mechanisms. The small number of participants was another concern of this study, which made it impossible to perform more sophisticated statistical analyses, such as regression models. Further studies with higher sample sizes will allow researchers to make more in-depth investigations of the complex interaction between different aspects of language processing and WM skills.

Conclusion

The results of the current study revealed that 6–8-year-old Persian-speaking children with DLD performed significantly weaker in lexical and grammatical aspects of language processing and non-word repetition, compared to typically developing age-matched children. Moreover, the considerable effect size in non-word repetition (d = 3.92) demonstrated the high magnitude of the difference between children with DLD and their TLD peers in terms of pSTM performance. Regarding the significant group-related differences between children with DLD and their TLD peers with considerable effect size, the non-word repetition could be proposed as a potential identifier for Persian-speaking children with DLD.

A series of one-way ANCOVA analysis provided supports for the idea that lexical and grammatical knowledge of children eventually affected by their phonological short-term memory skills. This finding has some valuable implications for clinical practice. Knowledge in the probable underlying cognitive mechanisms for poor word processing and grammar learning in children with DLD may provide more appropriate and focused approaches for the assessment and intervention.

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Compliance with Ethical Standards

Conflict of interest None.

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References

Adams, A.-M., & Gathercole, S. E. (1995). Phonological working memory and speech production in preschool children. *Journal of Speech, Language, and Hearing Research, 38*(2), 403–414.
Ahadi, H., & Mokhlesin, M. (2016). Correlation between phonological working memory, phonological awareness and language proficiency in tehran preschoolers. *Koomesh, 17,* 620–626.
Alt, M. (2011). Phonological working memory impairments in children with specific language impairment: Where does the problem lie? *Journal of Communication Disorders, 44*(2), 173–185.
Andrade, J., & Baddeley, A. (2011). The contribution of phonological short-term memory to artificial grammar learning. *Quarterly Journal of Experimental Psychology, 64*(5), 960–974.
Archibald, L. M. D. (2017). Working memory and language learning: A review. *Child Language Teaching and Therapy, 33*(1), 5–17.
Archibald, L. M. D., & Gathercole, S. E. (2006). Short-term and working memory in specific language impairment. *International Journal of Language and Communication Disorders, 41*(6), 675–693.
Archibald, L. M. D., & Gathercole, S. E. (2007). The complexities of complex memory span: Storage and processing deficits in specific language impairment. *Journal of Memory and Language, 57*(2), 177–194.
Baddeley, A. (2000). The episodic buffer: A new component of working memory? *Trends in Cognitive Sciences, 4*(11), 417–423.
Baddeley, A. (2003). Working memory and language: An overview. *Journal of Communication Disorders, 36*(3), 189–208.
Baddeley, A., Gathercole, S., & Papagno, C. (1998). The phonological loop as a language learning device. *Psychological Review, 105*(1), 158.

Baddeley, A., Papagno, C., & Vallar, G. (1988). When long-term learning depends on short-term storage. *Journal of Memory and Language, 27*(5), 586–595.

Bishop, D. V. M., North, T., & Donlan, C. (1996). Nonword repetition as a behavioural marker for inherited language impairment: Evidence from a twin study. *Journal of Child Psychology and Psychiatry, 37*(4), 391–403.

Bishop, D. V. M., Snowling, M. J., Thompson, P. A., & Greenhalgh, T. (2016). CATALISE: A multinational and multidisciplinary Delphi consensus study. Identifying language impairments in children. *PLoS ONE, 11*(7), e0158753.

Blake, J., Austin, W., Cannon, M., Lisus, A., & Vaughan, A. (1994). The relationship between memory span and measures of imitative and spontaneous language complexity in preschool children. *International Journal of Behavioral Development, 17*(1), 91–107.

Botting, N., & Conti-Ramsden, G. (2001). Non-word repetition and language development in children with specific language impairment (SLI). *International Journal of Language and Communication Disorders, 36*(4), 421–432.

Campbell, T., Dollaghan, C., Needleman, H., & Janosky, J. (1997). Reducing bias in language assessment: Processing-dependent measures. *Journal of Speech, Language, and Hearing Research, 40*(3), 519–525.

Dehn, M. J. (2011). *Working memory and academic learning: Assessment and intervention*. Hoboken: Wiley.

Dodwell, K., & Bavin, E. L. (2008). Children with specific language impairment: An investigation of their narratives and memory. *International Journal of Language and Communication Disorders, 43*(2), 201–218.

Duinmeijer, I., de Jong, J., & Scheper, A. (2012). Narrative abilities, memory and attention in children with a specific language impairment. *International Journal of Language and Communication Disorders, 47*(5), 542–555.

Durlak, J. A. (2009). How to select, calculate, and interpret effect sizes. *Journal of Pediatric Psychology, 34*(9), 917–928.

Estes, K. G., Evans, J. L., & Else-Quest, N. M. (2007). Differences in the nonword repetition performance of children with and without specific language impairment: A meta-analysis. *Journal of Speech, Language, and Hearing Research, 50*(1), 177–195.

Gagarina, N., Klop, D., Kunnari, S., Tantele, K., Välimaa, T., Balčiūnienė, I., & Walters, J. (2012). *MAIN: Multilingual assessment instrument for narratives*. Zentrum für Allgemeine Sprachwissenschaft.

Gathercole, S. E. (2006). Nonword repetition and word learning: The nature of the relationship. *Applied Psycholinguistics, 27*(4), 513–543.

Gathercole, S. E., & Baddeley, A. D. (1990). Phonological memory deficits in language disordered children: Is there a causal connection? *Journal of Memory and Language, 29*(3), 336–360.

Gathercole, S. E., Willis, C. S., Baddeley, A. D., & Emslie, H. (1994). The children's test of nonword repetition: A test of phonological working memory. *Memory, 2*(2), 103–127.

Gathercole, S. E., Willis, C. S., Emslie, H., & Baddeley, A. D. (1992). Phonological memory and vocabulary development during the early school years: A longitudinal study. *Developmental Psychology, 28*(5), 887.

Ghayoumi-Anaraki, Z., Haresabadi, F., Shahmahmood, T. M., Ebadi, A., Vakili, V., & Majidi, Z. (2018). The grammatical deficits of Persian-speaking children with specific language impairment. *Journal of Rehabilitation Sciences and Research, 4*(4), 102–108.

Haresabadi, F., Ebadi, A., Shirazi, T. S., & Dastjerdi Kazemi, M. (2016). Design and validation of a Photographic Expressive Persian Grammar Test for children aged 4–6 years. *Child Language Teaching and Therapy, 32*(2), 193–204.

Haresabadi, F., & Shirazi, T. S. (2015). Phonological working memory and auditory processing speed in children with specific language impairment. *Auditory and Vestibular Research*, *23*(6), 32–44.

Hassanzade, S., & Minayi, A. (2010). *Adopted from Newcomer PL, Hammill DD. Test Of Language Development, primary, 1997, 3rd.* Tehran: Institute of Education Studies Publication.

Hill, A. P., Van Santen, J., Gorman, K., Langhorst, B. H., & Fombonne, E. (2015). Memory in language-impaired children with and without autism. *Journal of Neurodevelopmental Disorders, 7*(1), 19.

Im-Bolter, N., Johnson, J., & Pascual-Leone, J. (2006). Processing limitations in children with specific language impairment: The role of executive function. *Child Development, 77*(6), 1822–1841.

Kazemi, Y. (2013). *Clinical assessment of Persian-speaking children with language impairment in Iran: Exploring the potential of language sample measures.* Doctoral Thesis, Newcastle University, Newcastle upon Tyne.

Kazemi, Y., Klee, T., & Stringer, H. (2015). Diagnostic accuracy of language sample measures with Persian-speaking preschool children. *Clinical Linguistics & Phonetics*, *29*(4), 304–318.

Kazemi, Y., & Saeednia, S. (2017). The clinical examination of non-word repetition tasks in identifying Persian-speaking children with primary language impairment. *International Journal of Pediatric Otorhinolaryngology, 93,* 7–12.

Kronenberger, W. G., Pisoni, D. B., Henning, S. C., Colson, B. G., & Hazzard, L. M. (2011). Working memory training for children with cochlear implants: A pilot study. *Journal of Speech, Language, and Hearing Research, 54*(4), 1182–1196.

Leonard, L. B., Weismer, S. E., Miller, C. A., Francis, D. J., Tomblin, J. B., & Kail, R. V. (2007). Speed of processing, working memory, and language impairment in children. *Journal of Speech, Language, and Hearing Research, 50*(2), 408–428.

Maleki Shahmahmood, T., Jalaie, S., Soleymani, Z., Haresabadi, F., & Nemati, P. (2016). A systematic review on diagnostic procedures for specific language impairment: The sensitivity and specificity issues. *Journal of Research in Medical Sciences: The Official Journal of Isfahan University of Medical Sciences, 21,* 67.

Maleki Shahmahmood, T., Soleymani, Z., & Faghihzade, S. (2011). The study of language performances of Persian children with specific language impairment. *Bimonthly Audiology-Tehran University of Medical Sciences, 20*(2), 11–21.

Maleki Shahmahmood, T., Soleymani, Z., Meysami, A., Mashhadi, A., & Nematzadeh, S. (2018). Cognitive and language intervention in primary language impairment: Studying the effectiveness of working memory training and direct language intervention on expansion of grammar and working memory capacities. *Child Language Teaching and Therapy, 34,* 235–268.

Marini, A., Gentili, C., Molteni, M., & Fabbro, F. (2014). Differential verbal working memory effects on linguistic production in children with specific language impairment. *Research in Developmental Disabilities, 35*(12), 3534–3542.

Marini, A., Ozbič, M., Magni, R., & Valeri, G. (2020). Toward a definition of the linguistic profile of children with autism spectrum disorder. *Frontiers in Psychology, 11,* 808.

Marini, A., Tavano, A., & Fabbro, F. (2008). Assessment of linguistic abilities in Italian children with specific language impairment. *Neuropsychologia, 46*(11), 2816–2823.

Montgomery, J. W. (2006). Real-time language processing in school-age children with specific language impairment. *International Journal of Language and Communication Disorders, 41*(3), 275–291.

Montgomery, J. W., Magimairaj, B. M., & Finney, M. C. (2010). Working memory and specific language impairment: An update on the relation and perspectives on assessment and treatment. *American Journal of Speech-Language Pathology, 19*(1), 78–94.

Norbury, C. (2017). Editorial: New frontiers in the scientific study of developmental language disorders. *Journal of Child Psychology and Psychiatry, 58*(10), 1065–1067.

Norbury, C. F., Gemmell, T., & Paul, R. (2014). Pragmatics abilities in narrative production: A cross-disorder comparison. *Journal of Child Language, 41*(3), 485–510.

Owen, A. J., & Leonard, L. B. (2002). Lexical diversity in the spontaneous speech of children with specific language impairment: Application of D. *Journal of Speech, Language, and Hearing Research, 45*(5), 927–937.

Peterson, R. L., Pennington, B. F., Samuelsson, S., Byrne, B., & Olson, R. K. (2013). Shared etiology of phonological memory and vocabulary deficits in school-age children. *Journal of Speech, Language, and Hearing Research, 56*(4), 1249–1259.

Ramachandra, V., Hewitt, L. E., & Brackenbury, T. (2011). The relationship between phonological memory, phonological sensitivity, and incidental word learning. *Journal of Psycholinguistic Research, 40*(2), 93–109.

Sansavini, A., Guarini, A., Alessandroni, R., Faldella, G., Giovanelli, G., & Salvioli, G. (2007). Are early grammatical and phonological working memory abilities affected by preterm birth? *Journal of Communication Disorders, 40*(3), 239–256.

Shahim, S. (2008). *Adaptation and standardization of Wechsler Intelligence scale for children—Revised (WISC-R)*. Shiraz: Shiraz University Publication.

Soleymani, Z., Amidfar, M., Dadgar, H., & Jalaie, S. (2014). Working memory in Farsi-speaking children with normal development and cochlear implant. *International Journal of Pediatric Otorhinolaryngology, 78*(4), 674–678.

Soleymani, Z., Nematzadeh, S., Tehrani, L. G., Rahgozar, M., & Schneider, P. (2016). Language sample analysis: Development of a valid language assessment tool and determining the reliability of outcome measures for Farsi-speaking children. *European Journal of Developmental Psychology, 13*(2), 275–291.

Stokes, S. F., Wong, A. M. Y., Fletcher, P., & Leonard, L. B. (2006). Nonword repetition and sentence repetition as clinical markers of specific language impairment: The case of Cantonese. *Journal of Speech, Language, and Hearing Research, 49*(2), 219–236.

Tomasello, M. (2000). Do young children have adult syntactic competence? *Cognition, 74*(3), 209–253.
Vugs, B., Hendriks, M., Cuperus, J., Knoors, H., & Verhoeven, L. (2017). Developmental associations between working memory and language in children with specific language impairment: A longitudinal Study. *Journal of Speech, Language, and Hearing Research, 60*(11), 3284–3294.
Vugs, B., Hendriks, M., Cuperus, J., & Verhoeven, L. (2014). Working memory performance and executive function behaviors in young children with SLI. *Research in Developmental Disabilities, 35*(1), 62–74.
Wetherell, D., Botting, N., & Conti-Ramsden, G. (2007a). Narrative skills in adolescents with a history of SLI in relation to non-verbal IQ scores. *Child Language Teaching and Therapy, 23*(1), 95–113.
Wetherell, D., Botting, N., & Conti-Ramsden, G. (2007b). Narrative in adolescent specific language impairment (SLI): A comparison with peers across two different narrative genres. *International Journal of Language and Communication Disorders, 42*(5), 583–605.
Williams, J. N., & Lovatt, P. (2003). Phonological memory and rule learning. *Language Learning, 53*(1), 67–121.

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