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VISUALLY SUPPORTED SHORT-TERM AUDITORY MEMORY IN CHILDREN WITH DEVELOPMENTAL LANGUAGE DISORDER (DLD)

Contributions:
A Study design/planning
B Data collection/entry
C Data analysis/statistics
D Data interpretation
E Preparation of manuscript
F Literature analysis/search
G Funds collection

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Abstract

Introduction: Developmental language disorder (DLD) is an impairment that disturbs the ability to acquire and make use of native language. The exact cognitive and neuronal brain underpinnings of the disorder are still a matter of investigation.

Material and methods: The relationship between the audiovisual phonemic short-term memory and particular language abilities was examined among 7–9 year-old children with DLD as well as in a gender, age, and IQ-matched control group. Children were assessed with a standard language battery and the Stanford–Binet scale (SB5). Subsequently, they performed a short-term memory task requiring immediate recall of sequences composed of syllables presented audiovisually.

Results: There were lower levels of audiovisual phonemic memory among children with DLD. They performed significantly worse than matched typically developing (TD) children in the experimental task and their performance was correlated with scores obtained in each language subtest. In contrast, we did not find between-group differences in visual short-term operational memory measured on the SB5 scale.

Conclusions: The present experiment replicated previous findings about short-term phonemic memory impairment in the DLD population. We found that memory impairment also occurs even if phoneme information is presented simultaneously in the auditory and visual domains. It appears that non-linguistic spatial cues accompanying phoneme stimuli do not overcome phonemic short-term memory impairment.

Key words: developmental language disorder • specific language disorder • DLD • SLI • short-term memory • phonemic memory • audio memory

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KRÓTKOTRWAŁA PAMIĘĆ SŁUCHOWA WSPOMAGANA WIZUALNIE U DZIECI Z ZABURZENIEM ROZWOJU JĘZYKOWEGO (DLD)

Streszczenie

Wprowadzenie: Rozwojowe zaburzenia językowe (ang. *developmental language disorder*, DLD) to upośledzenie, które zaburza zdolność nabywania i używania języka ojczystego. Dokładne poznawcze i neuronalne podstawy mózgowe tego zaburzenia są nadal przedmiotem badań.

Materiał i metody: W niniejszej pracy zbadano związek między audiowizualną foniczną pamięcią krótkotrwałą a poszczególnymi zdolnościami językowymi wśród 7–9-letnich dzieci z DLD oraz dopasowanej pod względem płci, wieku i IQ grupy kontrolnej. Dzieci były oceniane za pomocą standardowej baterii językowej oraz skali Stanford–Binet (SB5). Następnie wykonywały zadanie pamięci krótkotrwałej polegające na natychmiastowym przypominaniu sobie sekwencji składających się z sylab prezentowanych audiowizualnie.

Wyniki: Wyniki ujawniły obniżony poziom audiowizualnej pamięci fonemowej wśród dzieci z DLD. Dzieci te wypadły istotnie gorzej niż dzieci typowo się rozwijające (TD) w zadaniu eksperymentalnym, a ich wyniki były skorelowane z wynikami uzyskanymi w poszczególnych podtestach językowych. Nie stwierdzono natomiast różnic między grupami w zakresie wzrokowej krótkotrwałej pamięci operacyjnej ze skali SB5.

Wnioski: Obecny eksperyment zreplikował wcześniejsze ustalenia dotyczące upośledzenia krótkotrwałej pamięci fonemowej w populacji DLD. Stwierdziliśmy, że upośledzenie pamięci występuje również wtedy, gdy informacja fonemowa jest prezentowana jednocześnie w domenie słuchowej i wzrokowej. Stwierdziliśmy również, że nielingwistyczne wskazówki przestrzenne towarzyszące bodźcom fonemowym nie niwelują upośledzenia fonicznej pamięci krótkotrwałej w populacji DLD.

Słowa kluczowe: rozwojowe zaburzenie językowe • specyficzne zaburzenie językowe • DLD • SLI • pamięć krótkotrwała • pamięć fonematyczna • pamięć słuchowa

Introduction

Developmental language disorder (DLD) is an impaired ability to acquire and make use of language. It has a strong genetic component [1]. Although there is no identified underlying structural pathology of the brain in DLD, findings suggest there is atypical functional organisation of regions involved in language learning. The prevalence of DLD has been estimated at around 5–7% [2]. The term presently accepted in the research literature is *developmental language disorder* (DLD), but other terms are common among clinical practitioners and scientists [3]. As a consequence of communication deficits, children with DLD often experience difficulties in social, emotional, and behavioural domains [4,5]. They also face poorer academic performance and difficulties in starting and maintaining friendships [6].

The impairments present in DLD may encompass all aspects of language abilities. Specifically, the deficits may include phonology, vocabulary, morphology, and syntax [7]. DLD is defined by a set of inclusion criteria that are typically based on standardised language fluency and grammar tests. DLD was previously known as Specific Language Impairment (SLI), defined by a set of exclusion criteria, including having non-verbal IQ within the average range [7–9]. However, a contemporary view of the disorder has since recognized that many children with language impairment have comorbid challenges in cognitive ability beyond verbal abilities, such as poorer attention [10], difficulties in short-term or working memory, executive functions, and social cognition (e.g. theory of mind) [11]. As a result, many authors suggest excluding the term "specific" in reference to developmental language disorder [12] so that the present consensus focuses on the term *developmental language disorder* (DLD) which is used for language impairments of unknown etiology [3,13].

Importantly, DLD is a broad term referring to diverse problems that can manifest among different sets of language difficulties or phenotypes. Previous studies on a large sample of children with DLD identified subtypes of speech and language impairments, including *lexical–semantic, speech production, syntactic–sequential*, and *auditory perception* [14]. On the other hand, there is growing evidence that language impairments occur on a continuum rather than dichotomously [15]. Despite these inconsistencies, there is still a need to further investigate the basic cognitive mechanisms that are involved in observed linguistic disabilities in DLD and to clarify how they relate to particular language abilities.

One of the areas of DLD research is how deficits in sensory memory impair learning mechanisms. The integrity of sensory memory is essential for efficient auditory and speech perception and learning. To identify verbal information (speech), rapid segmentation of the incoming sounds need to be performed. However, rapid auditory inputs are susceptible to masking effects from preceding and succeeding sounds, and this will tend to impair perception [16]. Further, in order to identify words and sentences and their syntactic and grammar relationships, it is necessary to maintain phonetic and verbal inputs to sensory memory [17,18].

Previous research has shown that lower level auditory phonemic abilities and auditory memory may be impaired in children with DLD. Some results suggest co-occurring impairments of central auditory processing and DLD [19], with overlapping symptoms of central auditory disorder among children diagnosed with DLD [20]. Furthermore, a recent review of large datasets suggests that, when DLD children need to comprehend canonical and noncanonical sentences, working memory and attention play a key role in their ability to apply syntactic knowledge [21]. Results from a Persian population have shown that 6–8 year-old children with DLD experience significant difficulties in phonological short-term memory skills. Importantly, these difficulties seem to affect their lexical and grammatical performances [22].

Turning to EEGs, the possible deficits of auditory short-term memory among children with DLD (and their relatives) have been investigated using neurophysiological markers of cognitive processes. The EEG study of Barry et al. [23] looked at neural mechanisms of memory impairments in DLD, and revealed that the MMN ERP (mismatch negativity of the event-related potential) is diminished in DLD when the inter-trial interval is long, but not when the interval before recall was short. Barry et al. therefore suggest that in DLD there is shorter sensory memory and a vulnerability to acoustic masking effects [23].

It therefore seems as if such deficits create difficulties in identifying speech sounds. The deficits may also lower the ability to integrate information over time, an ability which is necessary for memorising multiple inputs and understanding complex speech. This is supported by results in adults who were parents of children with DLD which showed that MMNs were not elicited by changes within words [23] (for review see [24]). Additionally, some EEG studies report different effects in late ERP components, including P300 and N400, suggesting that there is an impaired ability to interpret and categorise acoustic stimuli [25,26].

The data indicate dual deficits – in verbal short-term and working memory – greater than the language ability criteria characteristic of DLD, and these deficits may plausibly underpin some of the language learning difficulties experienced by such children. Importantly, the visuospatial short-term and working memory abilities among children with DLD are typically reported at appropriate levels [17], indicating that impairments relate specifically to verbal and phonetic stimuli. The question then arises whether visual stimuli can assist in remembering acoustic information so that they support the memory of phonemic information and reduce difficulties among DLD children.

Consequently, we have studies the audiovisual memory of children with DLD and compared them with those of typically developing (TD) controls. We investigated the relationship between audiovisual phonemic short-term memory and language ability (measured by a Polish standardised language battery) in 7–9 year-old children with DLD as well as in a gender, age, and IQ-matched TD control group. We also examined the correlation between auditory short-term memory and the non-verbal memory subtest from the Stanford–Binet Intelligence Scale, Fifth Edition (SB5) [27].

Table 1. Group descriptive statistics

Demographic variables	TD $N = 21$		DLD $N = 16$		Mean difference	p	Effect size
	Mean	SD	Mean	SD			
Number of boys	12		10			0.74 A	
Age	8.0	0.67	7.9	0.8	0.1	0.70 B	
Nonverbal IQ SB5	110.2	9.50	104.5	11.0	5.7	0.10 B	
Language Development Test centile	82.3	13.87	18.1	11.6	64.2	< .001 B	4.95

A. Group difference calculated with Chi-Square. B. Group difference calculated with Student's *t* with effect size calculated with Cohen's *d*.

We hypothesised that auditory phonemic short-term memory will correlate with those linguistic abilities that depend strongly on declarative memory (including vocabulary span). We also hypothesised that, among the examined children, the size of audio-visual phonemic memory will be moderately related to non-verbal memory capacity.

Material and methods

Participants

There were 16 children with DLD (10 male, 6 female) and 21 TD children (12 male, 9 female) who participated in the study. The groups were not significantly different in size ($\chi^2(1,37) = 0.7$, $p = 0.4$). The average age in the DLD group was 7.9 (SD = 0.81) and for TD it was 8.0 (SD = 0.67). Identification of the DLD children involved an in-depth interview with their parents and a set of psychological assessments to evaluate the participants' linguistic as well as non-verbal functioning. Language functioning was examined using the Polish version of the Language Development Test (*Test Rozwoju Językowego*). Only children whose overall language level or score on any subscale of the LDT was very low (below 1.5 SD) were eligible for the DLD group. Additionally, in the DLD group, 6 children had a special educational needs statement (category e – *with motor disabilities, including aphasia*). Parents provided detailed information about their child's development, possible diagnosis of ASD, ADHD, or other developmental/neurological condition, and about hearing assessment. All children with language difficulties had a hearing assessment in their medical history, and none of them had hearing impairment. Children in the present study also participated in an fMRI/MRI examination and brain damage/disease was excluded.

The groups did not differ in age, gender, overall score on the intelligence test, or any of its subscales. The overall language functioning and performance on each subscale differed significantly between the groups. Descriptive statistics can be found in **Table 1**.

Ethical approval for the study was obtained from the Bioethics Committee of the Institute of Physiology and Pathology of Hearing in Warsaw. Informed written consent was given by the children's parents prior to participation.

Cognitive tests

The subjects participated in tests assessing their cognitive function. Non-verbal intelligence was measured using the non-verbal section of the Stanford–Binet Intelligence Test 5 (SB5). Nonverbal IQ in the DLD group ranged from 87 to 129. In the control group, IQ ranged from 94 to 129. Scores for individual subscales in the intelligence test were converted to a standard scale ranging between 1 and 19 with a population mean of 10.

Raw scores on the LDT were converted to percentiles (ranging from 0 to 100). In the DLD group, LDT scores ranged from 0 to 34 percentiles; in the control group, scores on the language test were between the 48th and 100th percentile. The individual subscales of the language test were converted to a stanine scale, which ranged from 1 to 9 with a population mean of 5 and a standard deviation of 2. Group scores for each subscale can be found in **Table 2**.

Audiovisual phonemic memory task (AVMT)

Subjects were asked to carefully listen to a sequence made up of the syllables "za" and "ma" and then reproduce it in the correct order. The complete AVMT procedure is illustrated in **Figure 1**. The test subjects were first given pictorial and auditory instructions that informed them about the task's purpose. The task was also explained verbally by the researcher to ensure that the subject understood it. Then the sequence required to be memorised was presented (2, 3, 4, or 5 syllables at an interval of 1 s). The auditory presentation of the syllables was visually supported by the letters "Z" and "M", which were highlighted on the screen during the presentation of each syllable. After that, a screen was presented for 2 s ("Now it's your turn") before the respondent keyed in the sequence heard earlier. Sequences of each length for each subject were randomly selected from a pool. For each sequence length participants completed three consecutive trials. Consequently, for each memory span (sequence length), a subject had the opportunity to score from 0 to 3 points. The scheme of the task was as follows: 3 × 2 syllables, 3 × 3 syllables, 3 × 4 syllables, and 3 × 5 syllables. Three incorrect recalls of the sequence in a row terminated the task. For each memory span, the participant could score from 0 to 3 points. The overall score in the auditory-visual phonemic memory task was calculated as the sum of correctly recalled sequences for each type of sequence and could range from 0 to 12.

Table 2. Detailed group scores for each subscale in the Stanford–Binet Intelligence Test 5 and the Language Development Test

Cognitive variables	TD		DLD		Mean difference	*p*	Effect size
	Mean	SD	Mean	SD			
Stanford–Binet 5 Non-verbal subscales							
Fluid reasoning	10.8	3.34	9.9	2.3	0.9	0.34 A	
Knowledge	11.9	3.55	11.7	2.8	0.2	0.84 A	
Quantitative reasoning	10.0	2.49	9.3	3.0	0.7	0.45 A	
Visual-spatial processing	12.1	1.51	11.1	2.7	1.0	0.15 A	
Working memory	12.6	2.82	11.8	3.0	0.8	0.40 A	
Language Development Test subscales							
Language uderstanding (overall)	5.8	1.73	2.6	1.1	3.2	< .001 A	2.15
Word comprehension	5.8	1.78	2.6	1.3	3.2	< .001 A	2.02
Sentence comprehension	5.5	1.86	2.6	1.4	3.0	< .001 B	0.77
Text comprehension	6.5	1.69	3.8	1.3	2.7	< .001 A	1.78
Language producton (overall)	6.1	1.67	1.9	0.9	4.0	< .001 B	0.97
Word production	6.1	1.81	2.7	1.3	3.4	< .001 A	2.13
Sentence repetition	5.7	1.68	1.8	1.0	3.9	< .001 A	2.71
Word declension	5.7	1.43	2.6	1.3	3.0	< .001 B	0.87

A. Group difference calculated with Student's *t* with effect size calculated with Cohen's *d*. B. Group difference calculated with Mann–Whiney *U* with effect size calculated with rank biserial correlation.

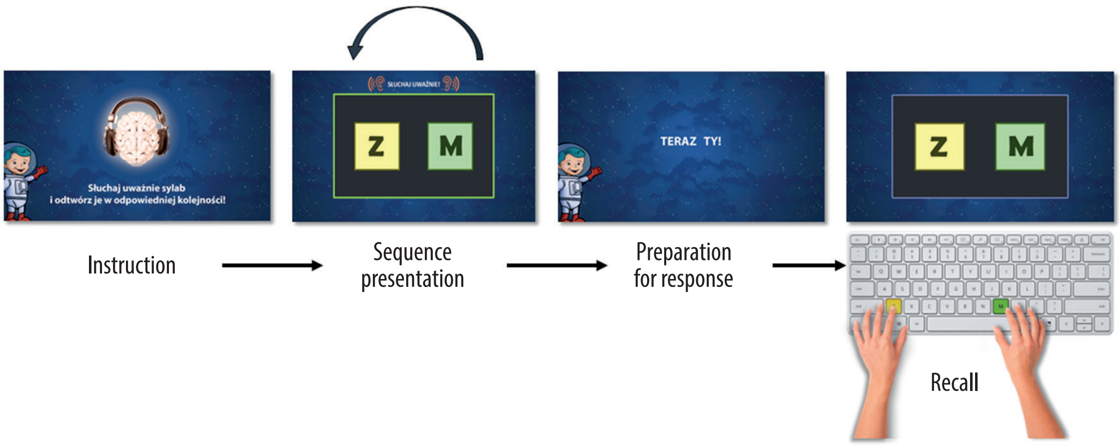

Figure 1. Schematic of the Audio-Visual Phonemic Memory Task (AVMT). The instruction (panel 1) was followed by a sequence of 2 to 5 syllables (made up of the syllables "za" and "ma") which needed to be memorised (panel 2). The syllables were presented both aurally and visually (for example, in the form of the letters "Z" and "M" corresponding to the syllables "za" and "ma"). Then a screen displays "Now it's your turn" (panel 3), at which point the subject has to key in the correct sequence (panel 4)

Statistical analysis

All analyses were performed using normalised data (percentiles and stanine values). Due to the low *p*-value in the Shapiro–Wilk test of the AVMT scores ($p < 0.01$), indicating a non-normal distribution of scores, group differences in the AVMT were calculated using a Mann–Whitney *U*-test. A Spearman's rank correlation was computed between the AVMT and language functioning as well as with non-verbal intelligence. In addition, we wanted to test whether the groups differed in their performance of AVMT across different levels of working memory. For each memory span (number of syllables), a subject had the opportunity to score from 0 to 3 points. Scores for each memory span were submitted to a two-way multivariate analysis of variance with repeated measures (ANOVA).

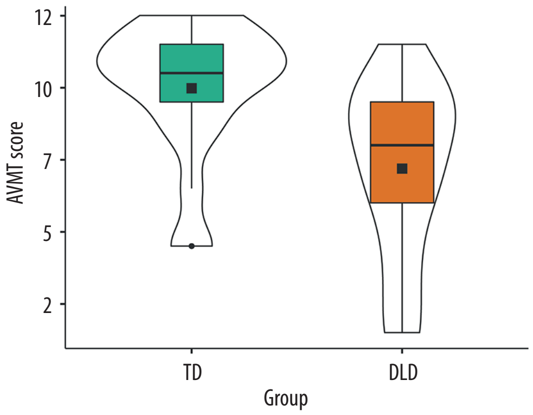

Figure 2. Violin plots of the distribution of the AVMT scores for each group. Group means are marked with black squares

The between-subjects variable was *group* (DLD vs TD), and the within-subject variable was *memory span* (2, 3, 4, or 5 syllables). All effects with more than one degree of freedom in the numerator were adjusted for violations of sphericity according to the Greenhouse–Geisser formula. Post hoc analyses were calculated using Bonferroni correction. All statistical analyses were conducted in Jamovi software (version 2.2.5).

Results

The audiovisual memory task was able to significantly differentiate children with DLD from typically developing children ($U = 69$; $p = 0.002$). The effect size, calculated as rank-biserial correlation, reached 0.59. Children with DLD performed significantly worse than TD children, even though the auditory memory task was supported by visual information and even though the groups did not differ in their performance on the SB5 working memory test. TD children achieved a mean score of $M = 9.5$ (SD = 2.3), whereas DLD children obtained $M = 6.7$ (SD = 3.1). The median score for DLD was 7.5 and for the TD group it was 10. The distribution of the scores among the groups is shown in **Figure 2**.

Performance on the AVMT correlated significantly with the other tested variables. General language functioning, understood as the overall percentile on the LDT, correlated with the score on the audiovisual task ($r(35) = 0.46$; $p = 0.004$). We noted a significant relationship not only with the overall percentile on the LDT test but also with all its subscales. Word comprehension was found to be the strongest correlated factor ($r(35) = 0.59$; $p < 0.001$). Nonverbal intelligence, although it did not differ between the groups, correlated significantly with scores on the auditory memory task ($r(35) = 0.4$; $p = 0.014$). However, this factor played a significant role only overall, as there was no significant correlation for any of the subscales on the SB5 IQ test. Looking at the relationship between intelligence and AVMT performance by group (**Figure 3**), the correlation was only significant for the DLD group ($r(15) = 0.58$, $p = 0.018$), not for TD children ($r(19) = 0.17$, $p = 0.46$). The exact correlations for each subscale are shown in **Table 3**. Plots of significant correlations are shown in **Figure 4**.

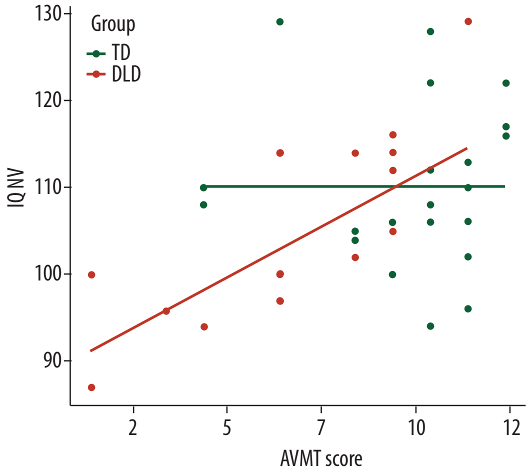

Figure 3. Correlations between nonverbal IQ and AVMT scores

In addition, we wanted to test whether the groups differed in their AVMT performance according to working memory load. The average number of correctly recalled sequences for each number of syllables (2, 3, 4, or 5 syllables), along with the median score and standard deviation for each group, are shown in **Table 4**. On average, children with DLD had a lesser number of correct answers for each sequence type, and the average difference in scores between the groups increased as the number of syllables required to be memorised grew. The distribution of responses across groups is shown in **Figure 5**.

We found a significant simple effect of group ($F(1,35) = 9.22$, $p = 0.005$, $\eta^2 = 0.21$) and an effect of memory load ($F(3,105) = 21.18$, $p < 0.001$, $\eta^2 = 0.38$). Post hoc analyses showed that, regardless of the group, there were significant differences between the correctness of task execution for 2 syllables vs 4 syllables and 5 syllables; for 3 syllables vs 4 syllables and 5 syllables; and for 4 syllables vs 5 syllables. We did not see a significant interaction effect between group and memory load ($F(3,105) = 0.3$, $p = 0.78$). This indicates that although the groups differed in terms of AVMT performance, the numerical correctness of both groups decreased in line with the increase in the number of syllables required to be memorised. The change in the number of correct answers with increasing memory load is shown in **Figure 6** for each group.

Discussion

The results of our investigation showed that children with DLD had reduced levels of audiovisual phonemic memory. They performed significantly worse than TD children in the task of immediate recall of a sequence of syllables presented audiovisually. In contrast, we did not find any between-group differences in visual short-term operational memory derived from the SB5 scale.

Further analysis showed that audiovisual phonemic memory scores correlated significantly with the overall score on the standardised Language Development Test used for DLD diagnosis. Interestingly, all language subtests were found to correlate significantly with performance on the

Table 3. Correlations between overall results in the AVMT and each subscale in the Stanford–Binet Intelligence Test 5 and the Language Development Test (*N* = 37)

Cognitive variables	*N* = 37	
	Spearman's Rho	*p*
Stanford–Binet 5 Non-verbal	**0.40**	**0.01**
Fluid reasoning		0.12
Knowledge		0.49
Quantitative reasoning		0.23
Visual-spatial processing		0.16
Working memory		0.33
Language Development Test	**0.46**	**0.004**
Language uderstanding (overall)	0.52	0.001
Word comprehension	0.59	< 0.001
Sentence comprehension	0.37	0.026
Text comprehension	0.44	0.007
Language producton (overall)	0.43	0.008
Word production	0.37	0.024
Sentence repetition	0.36	0.029
Word declension	0.37	0.025

experimental audiovisual memory task (see **Table 3**). We also found that, in case of DLD children, audiovisual phonemic memory scores correlated significantly with overall nonverbal IQ. This effect was absent in the TD control group.

The results presented here replicate previous findings that showed short-term memory impairment for auditory and/or phonemic stimuli among children with DLD. For example, it has been found that auditory memory for nonsense syllables largely accounts for the variance in expressive language measures [28]. Further, a longitudinal study of 97 children with SLI/DLD, 5–6 years old, revealed that short-term auditory memory plays an important role in language acquisition among children with SLI/DLD [29]. A recent large sample study of 5–8 year-old children with DLD, alongside TD controls, demonstrated group differences in several verbal memory tasks [30]. Specifically, participants with DLD demonstrated impairments in verbal short-term and working memory. Children with DLD also scored lower in verbal declarative memory, and procedural memory tasks; however, after controlling for working memory and nonverbal IQ, these abilities were no longer impaired. In conclusion, the authors suggest that deficits in learning the language material can largely be accounted for by poorer working memory skills [30]. Our results, together with previous findings, therefore support the notion that deficits in short-term auditory memory of basic linguistic information contribute to developmental difficulties in language acquisition among children with DLD.

The audiovisual task used in our experiment was designed to test whether multisensory memory is also impaired in children with DLD. In this investigation, we included a memory task with two types of phonemic information: auditory-phonemic and visual-graphemic. Children with DLD appeared to perform significantly worse than TD children in the audiovisual memory task. This result can also be viewed in the context of co-occurring symptoms of dyslexia. Previous studies have shown that, for children with SLI/DLD, literacy abilities are also impaired [31], and many such children had considerable literacy difficulties when they first entered school [32,33]. In line with our results, children with DLD are known to have difficulties in memorising phonemes, and many also struggle to learn graphemes when learning to read and write [32,34].

Our results support the notion that disruptions in phonological coding also appear in multimodal tasks. An early study by Gillam and colleagues [35], based on 8–11 year-old children with SLI/DLD, investigated the short-term memory of digits that were presented auditorily, visually, or audiovisually. The task required two types of responses: speaking and pointing. The study revealed that, under both modalities, children with DLD recalled fewer items than children in the control group. However, performance was significantly poorer when the required response was pointing rather than speaking. In discussing their findings, the authors suggest that, in situations when a pointing response is required, an additional phonological recording step is needed to represent visual information and perform a motor response. One explanations is that deficiencies in phonological coding for DLD subjects may involve a limitation in the capacity to retain adequate representations across multiple processing conversions [35]. These findings suggest that short-term/working memory impairments are not modality-specific but rather involve supra-modal phonological processing.

It seems to be important that the short-term memory task we used included additional non-linguistic visuospatial cues (i.e., the visual representation of syllables appeared on the left or the right side of the screen, see **Figure 1**). Based on

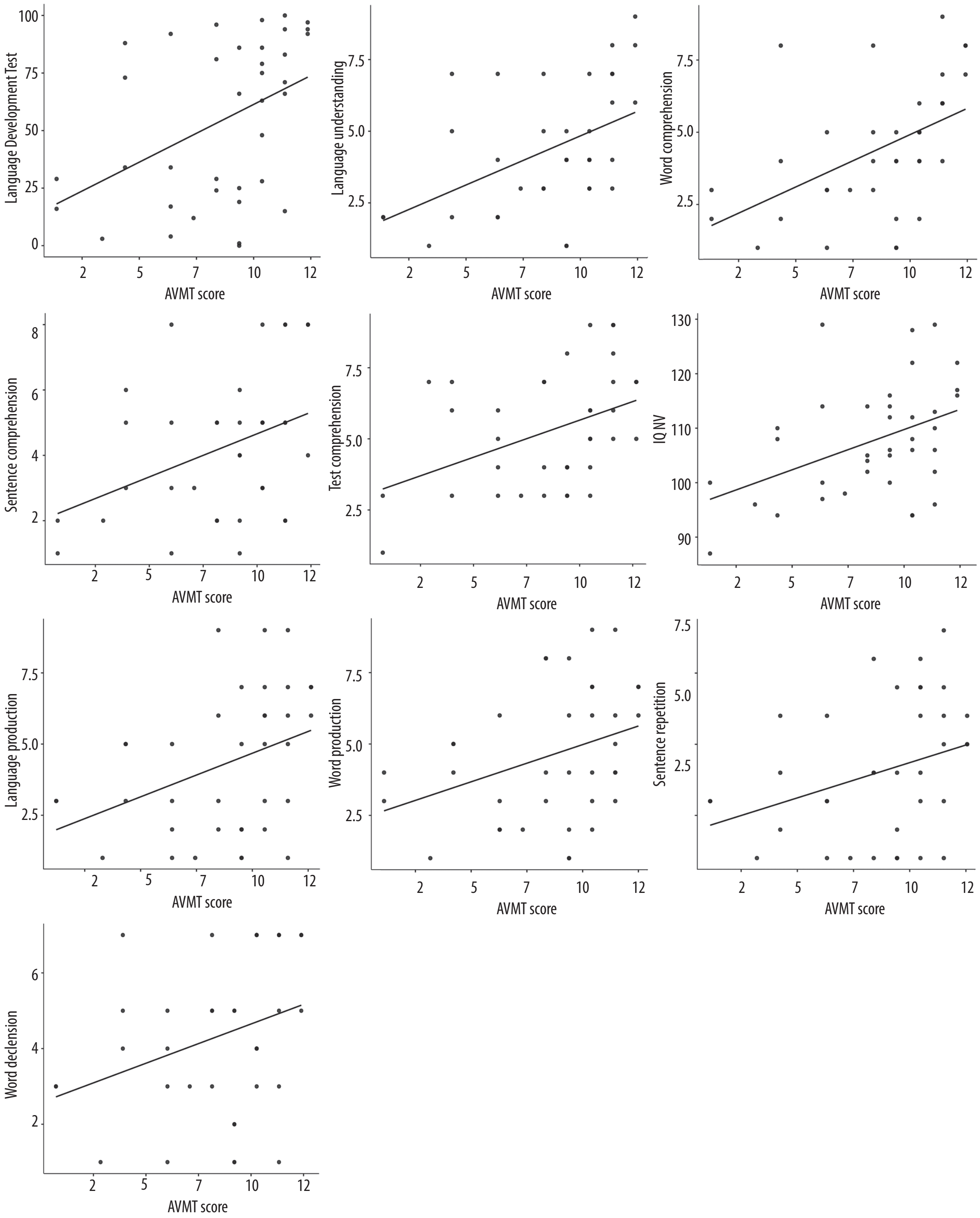

Figure 4. Significant correlations between overall results in the AVMT and each subscale in the Stanford–Binet Intelligence Test 5 and the Language Development Test

Table 4. Average group score by length of sequence required to be memorised

Number of syllables	TD			DLD			Mean difference
	Mean	Median	SD	Mean	Median	SD	
2 syllables	2.8	3	0.51	2.3	3	0.87	0.5
3 syllables	2.8	3	0.6	2.1	3	1.2	0.7
4 syllables	2.2	2	1.03	1.5	1.5	1.3	0.7
5 syllables	1.7	2	1.16	0.8	0.5	0.98	0.9

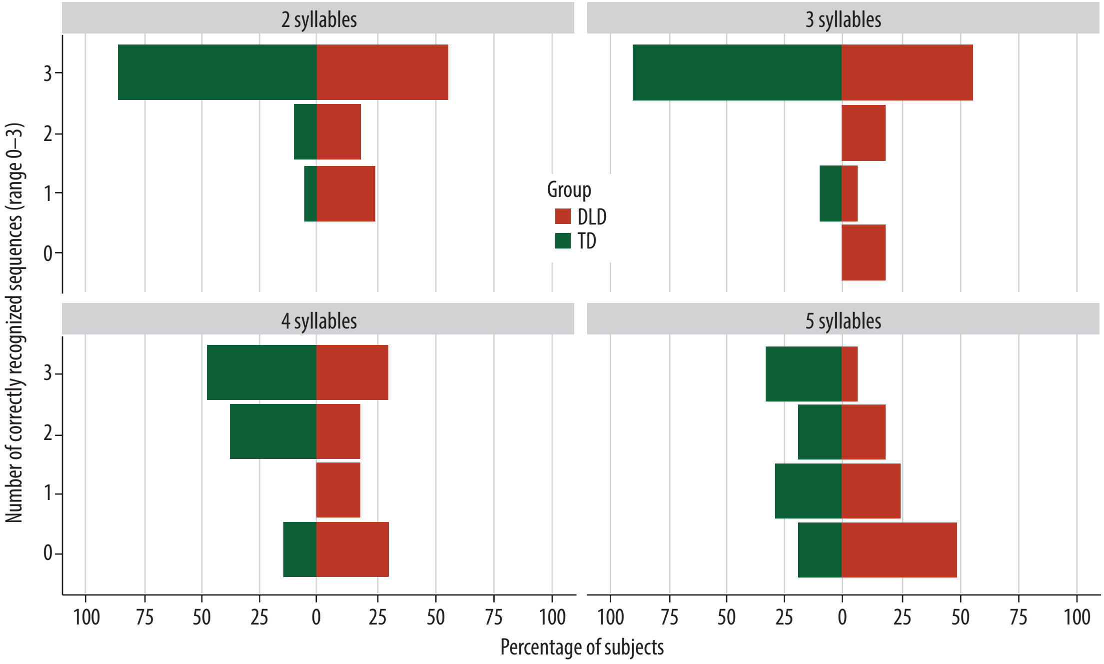

Figure 5. Number of correctly recalled sequences (out of 3 trials) when each sequence was made up of 2, 3, 4, or 5 syllables

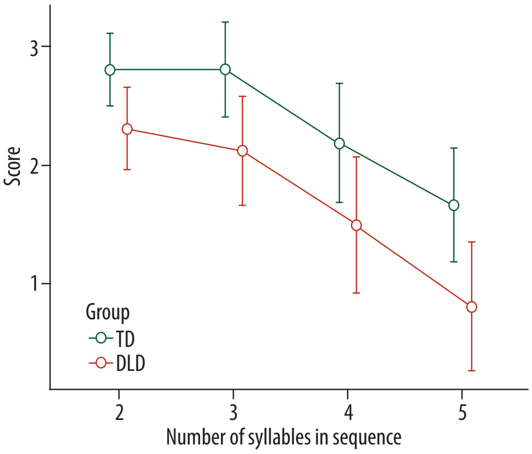

Figure 6. The average number of correctly repeated sequences as a function of the number of syllables that needed to be memorised. Circles indicate means and error bars indicate 95% confidence intervals

the results of our between-group analysis, we conclude that the visuospatial cues that supported phonemic information were insufficient to compensate for the impairment of phonemic memory in DLD. Children with DLD generally performed significantly worse, and their level of performance correlated with their diminished lexical abilities. Our results also show that only for children with DLD did the overall nonverbal IQ score correlate with performance on a short-term memory task. This was not the case for TD children. This probably indicates that, in multimodal tasks, children with DLD are more dependent on their nonverbal cognitive abilities, while children with TD primarily use their verbal/phonic abilities to process audiovisual information.

Importantly, we did not find a correlation between the results of our short-term memory task and the visuospatial memory task from the SB5 battery. Children with DLD were equally good at the SB5 memory task as were their TD peers. Similar results have previously been found in that non-verbal short-term and working memory is intact in DLD, while memory difficulties mainly involve verbal [36] and phonemic [31] stimuli. Our experiments indicate a new finding: that disruption of direct phonetic memory is present in DLD, even for audiovisual phonemic stimuli, and cannot be easily overcome by adding visuospatial cues. An additional interpretation comes from earlier findings in which the memory of verbally presented digits and of spatial locations was tested: children with DLD had poorer recall of both digits and locations across all experimental conditions [37]. Importantly, under multimodal conditions that enabled children to divide processing efforts across verbal and spatial response modalities, TD children derived greater benefits than did DLD children. The authors suggest that between-group differences in processing capacity result from a combination of storage and retrieval limitations in the verbal and spatial domains, as well as from response modality demands [37].

In concluding, our study, together with findings from previous investigations, suggests that when treating children with DLD therapeutically, adding visuospatial cues may not be helpful in acquiring basic linguistic information. In many cases, the extra cues may be more disruptive than beneficial. Instead, we suggest that increasing the number of repetitions and the period of training may help in improving phonemic/verbal memory and language learning in DLD children. This approach, however, should be further investigated in reference to children with developmental language impairments.

Conclusions

Our work replicated previous findings about short-term phonemic memory impairment in the DLD population. In addition, we found that this memory impairment also occurs when phonemic information is simultaneously presented in the auditory and visual domains. We also found that if non-linguistic spatial cues accompany phonemic stimuli, this does not eliminate the deficit in phonemic short-term memory. Finally, we found that phonemic short-term memory capacity correlates with all language abilities, including receptive and expressive skills. Interestingly, only in the DLD group did we find a significant correlation between short-term memory ability and nonverbal IQ.

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