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Working memory and vocabulary in children with Developmental Language Disorder

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Abstract

The aim of this study was to verify if there is a difference in performance between children with Developmental Language Disorder (DLD) and typical language development (TLD) in phonological working memory (PWM) test and visual short-term memory (VSTM), and if this performance is correlated with the result of a receptive vocabulary test. We selected 14 children with DLD and 28 with TLD. All subjects underwent two short-term memory tests and a receptive vocabulary test. The comparison between the groups was performed using the Student's t-test, and the correlation between the short-term memory and the vocabulary was obtained by Pearson's correlation. Children with DLD had a worse performance when compared with the control group, both in PWM and VSTM. The positive correlation between memory and vocabulary tests suggests that both the phonological loop and visual memory are important for the processing of language, even if the phonological loop may have greater relevance.

Keywords: cognition, working memory, phonological working memory, vocabulary, language development disorders

MEMÓRIA OPERACIONAL E VOCABULÁRIO EM CRIANÇAS COM TRANSTORNO DO DESENVOLVIMENTO DA LINGUAGEM

Resumo

O objetivo deste estudo foi verificar se existe diferença no desempenho de crianças com Transtorno do Desenvolvimento da Linguagem (TDL) e Desenvolvimento Típico de Linguagem (DTL) em testes de memória operacional fonológica (MOF) e de memória visual de curto prazo (MVCP), e se esse desempenho está correlacionado com o vocabulário receptivo. Selecionamos 14 crianças com TDL e 28 com DTL. Todos os sujeitos foram submetidos a dois testes de memória de curto prazo e a um teste de vocabulário receptivo. A comparação entre os grupos foi realizada por meio do Teste t de Student e a correlação entre a memória de curto prazo e o vocabulário foi obtida pela correlação de Pearson. Crianças com TDL tiveram pior desempenho quando comparadas ao grupo controle, tanto em MOF quanto em MVCP. A correlação positiva entre os testes de memória e vocabulário sugere que tanto a alça fonológica quanto a memória visual são importantes para o processamento da linguagem, mesmo que a alça fonológica possa ter maior relevância.

Palavras-chave: cognição, memória operacional, memória operacional fonológica, vocabulário, transtornos do desenvolvimento da linguagem

MEMORIA OPERATIVA Y VOCABULARIO EN NIÑOS CON TRASTORNO DEL DESARROLLO DEL LENGUAJE

Resumen

El objetivo de este estudio fue verificar si existe una diferencia en el desempeño de los niños con Trastorno del Desarrollo del Lenguaje (TDL) y el desarrollo del lenguaje típico (DLT) en las pruebas de memoria operativa fonológica (MOF) y memoria visual a corto plazo (MVCP), y si ese desempeño es co-

rrelacionado con el vocabulario receptivo. Seleccionamos 14 niños con TDL y 28 con DTL. Todos los sujetos se sometieron a dos pruebas de memoria a corto plazo y a una prueba de vocabulario receptivo. La comparación entre grupos se realizó mediante la prueba t de Student y la correlación entre la memoria a corto plazo y el vocabulario se obtuvo mediante la correlación de Pearson. Los niños con TDL tuvieron un peor desempeño en comparación con el grupo de control, tanto en la MOF como en la MVCP. La correlación positiva entre las pruebas de memoria y vocabulario sugiere que tanto el bucle fonológico como la memoria visual son importantes para el procesamiento del lenguaje, aunque el bucle fonológico puede tener mayor relevancia.

Palabras clave: cognición, memoria operativa, memoria operativa fonológica, vocabulario, trastornos del desarrollo del lenguaje

Developmental Language Disorder (DLD) is the new term to replace specific language impairment (Bishop et al., 2017). It is diagnosed when children fail to acquire their own language for no obvious reason. These children present a difficulty to understand what people say to them and struggle to articulate their ideas and feelings.

DLD is a subset of language disorder, which is itself a subset of the broader category of speech, language, and communication needs. It has a multifactorial etiology, is heterogeneous in terms of language features, and overlaps with other neurodevelopmental disorders (Laasonen et al., 2018). It is a hidden disability that affects approximately two children in every classroom, hindering literacy, learning, friendships, and emotional well-being. A recent epidemiological study in the United Kingdom – UK (Norbury et al., 2016) found that 7.5% of children had DLD, with no associated biomedical condition.

It is not entirely clear how the linguistic deficit in DLD is processed. Among the hypotheses to explain linguistic difficulties in DLD is the short-term memory deficit, particularly the phonological component of the working memory (WM). Memory is a complex cognitive system with numerous subdivisions. It is usually divided into short-term and long-term memory. Short-term memory is the capacity to store a small amount of information in mind and keep it readily available for a short period of time. Researchers argue that WM and short-term memory significantly overlap, and may even be the same thing. However, the distinction that is often made is that WM refers to the ability to use, manipulate, and apply memory for a period of time, while short-term memory refers to the temporary storage of information in memory (Chai et al., 2018; Zlotnik & Vansintjan, 2019). The Baddeley-Hitch model of WM suggests that WM has two main components: a system in which you store visual and spatial information (visuospatial scratchpad), and a system in which you record auditory information (phonological loop). In addition, the model points to a third part (central executive), which controls and mediates these two components, as well as processes information, directs attention, sets goals, and makes decisions (Baddeley, 2006).

The WM is a multicomponent system that involves the retention of information for a short period of time, in order to assist cognitive tasks (Baddeley, 2006). It comprises four integrated components: central executive, phonological loop, visuospatial network, and episodic buffer. The central executive component is responsible for regulating the flow of information; the phonological loop stores phonological data for a short period of time and is responsible for the rehearsal loop (or reverberation) that keeps information active in memory; the visuospatial network is in charge of maintaining and processing visual and spatial information; the episodic buffer integrates information from the three previous systems with long-term memory, making it conscious.

The phonological component of WM – phonological working memory (PWM) – plays a role in the process of learning phonological forms not yet learned, such as new words. The model of WM posits a reciprocal relationship between phonological short-term memory and

vocabulary knowledge, which becomes increasingly reciprocal after the age of five (Baddeley, 2006). A varied vocabulary would assist new word learning, as the learner has prior lexical knowledge from which to draw to support the learning of new phonological and semantic forms. Good phonological short-term memory facilitates vocabulary development, given its role in temporarily storing new phonological information (Jackson et al., 2016). It is argued that weaknesses in holding in mind verbal information over short periods of time could negatively impact the child's ability to create accurate and stable long-term representations for new words and, therefore, affect vocabulary development (Henry & Botting, 2017). In support of this position, weak verbal short-term memory is one of the most consistent findings in the literature on children with DLD (Lum et al., 2012; Vugs et al., 2016; Archibald, 2017).

While the relationship between PWM deficit and DLD has been strongly demonstrated, including studies of Brazilian Portuguese-speaking children (Cáceres-Assenço et al., 2014; Hage et al., 2014), the role of other memory skills is less explored, like visual short-term memory (VSTM). VSTM refers to the active maintenance of visual information for a short period. Short-term visual memory helps us remember objects for a short period of time when those objects or figures are no longer visible and it seems to be more complex than has long been assumed (Liu et al., 2020). Regarding the relationship between DLD and VSTM, there is no consistent evidence to confirm or not a deficit (Henry et al., 2012), which indicates that studies in this field deserve attention.

Thus, studies that can contribute to the understanding of the relationship between short-term memory and vocabulary development are crucial and can significantly contribute to the language difficulties experienced by these children. It is important to emphasize that memory research can provide important information about how memory works in these children and contribute to better-targeted intervention programs. In this context, this study aimed to verify the relationship between phonological working, visual memory, and receptive vocabulary in children with DLD.

Method

Ethics statement

The study was approved by the Research and Ethics Committee of the Bauru School of Dentistry of the University of São Paulo (Universidade de São Paulo [USP]), registered under process No. 70/2009. Written informed consent was obtained from a parent or legal guardian.

Participants

We selected 42 children, ages ranging between five and ten years of both genders. Fourteen of them presented with DLD – study group (SG) –, and 28 had typical language development – comparative group (CG). They were matched for chronological age and school grade. Despite a recent epidemiological study in the UK indicating that 7.5% of children had

DLD (Norbury et al., 2016), in Brazil, the diagnosis is uncommon. Brazilian law does not yet cover language disorders not associated with a biomedical condition, as occurs in other countries, such as in the UK, Spain, and United States. Hence, the identification of these children is not common in child-care centers, leading the research with this population to have a more restricted number of subjects.

Study group

The children of the SG were selected from patients diagnosed with DLD by a multidisciplinary team, including a speech pathologist, an audiologist, a neuropsychologist, and a neurologist. Inclusion criteria were the diagnosis of DLD, according to the criteria proposed by Bishop (2017): performance in language tests and analysis of samples of oral language lower than that expected for the mental and chronological age, covering expression and/or understanding; having a hearing threshold within normal limits; all children did not meet criteria for intellectual disability, Autism Spectrum Disorder, or any other biomedical condition.

Comparative group

The children of the CG were selected from two elementary schools. Inclusion criteria for subjects in the CG were: no history of abnormal development of oral language and hearing; and a school performance compatible with the age and level of education. To meet the inclusion criteria, the teachers were questioned about possible deficits in their students' oral language, listening, and school performance. Those who had a history or complaint of difficulties in one or more of these factors were excluded from the sample.

Procedures

All subjects underwent three tests: PWM, VSTM, and receptive vocabulary.

- Phonological working memory (PWM): assesses phonological loop, it is a non-word repetition test (Hage & Grivol, 2009) that aims to evaluate the number of items that the individual can retain and retrieve from the memory immediately after the oral presentation of a list of non-words. To be considered an appropriate response, the repetition should be identical to that presented by the examiner, with the examiner being allowed to repeat every word only once. The presence of phonological simplifications in the case of children with DLD had been previously noted in the answer sheet and was not considered part of the errors of repetition. Before the non-word repetition test, the subjects with DLD were submitted to the ABFW phonology test (Wertzner, 2016) to determine if there were possible phonological disorders.

- Visual short-term memory (VSTM): the pictorial memory test (Rueda & Sisto, 2007) is a visual memory test that assesses people's ability to retrieve information in a short period of time, through pictorial stimuli and represented by concrete nouns, characterized as a measure of short-term memory. The test results represent a visual memory response by the number of remembered pictures, but it does not determine the spatial aspect, that is, where the object was in the picture. This test comprises a picture containing 55 drawings organized into three categories: water, sky, and earth. The participant has 90 seconds to analyze the images and, in a sequence, 120 more seconds to write down the names of the images they recognize from the drawings. All children were asked to speak the names of the images out loud since some of them were not literate. To avoid the possibility that the visual retention of the images could have any interference in the lack of knowledge of the image name, all of them were named more than once by the examiner, prior to the testing process.
- The receptive vocabulary test: adapted and reviewed Spanish version of the Peabody Picture Vocabulary Test-third edition (PPVT-III) (Dunn et al., 2006). The test is composed of 204 pictures. In it, the examiner says a word out loud (target element) and the patient points out, among four possibilities, which image best represents the spoken word. A commercial version of the PPVT-III for the Portuguese language is not available; therefore, two independent translations were carried out by two bilingual speech pathologists, generating two different versions referred to as translation 1 (T1) and translation 2 (T2). T1 and T2 were then brought together to produce a third translation, referred to as translation 3 (T3), or synthesis version. T3 was then translated back (backtranslation) to Spanish by a native Spanish speaker who is familiar with the Portuguese language, producing a final version in Spanish. This final version was compared to the original Spanish version, in order to verify possible inconsistencies. The final version was applied to a group of ten Brazilian children to create a baseline score.

Statistical analysis

The comparison between the groups was carried out by the Student's T-test. The correlation between the short-term memory test and the vocabulary test was obtained by Pearson's correlation coefficient. In all statistical tests, the significance level was 5% ($p < 0.05$).

Results

Table 1 shows the distribution of subjects by age and gender, both for the SG and CG.

Table 1

Distribution of subjects by age and gender, both for the group with DLD and for the comparative group

Subject No.	Group	Gender	Age
1	DLD	Male	8;11
2	COMPARATIVE	Male	8;11
3	COMPARATIVE	Male	8;11
4	DLD	Male	5;6
5	COMPARATIVE	Male	5;6
6	COMPARATIVE	Female	5;6
7	DLD	Male	5;10
8	COMPARATIVE	Female	5;10
9	COMPARATIVE	Male	5;10
10	DLD	Male	9;5
11	COMPARATIVE	Female	9;5
12	COMPARATIVE	Male	9;5
13	DLD	Female	8;0
14	COMPARATIVE	Female	8;0
15	COMPARATIVE	Female	8;0
16	DLD	Male	10;8
17	COMPARATIVE	Male	10;8
18	COMPARATIVE	Male	10;8
19	DLD	Female	9;0
20	COMPARATIVE	Female	9;0
21	COMPARATIVE	Female	9;0
22	DLD	Male	5;7
23	COMPARATIVE	Male	5;7
24	COMPARATIVE	Male	5;7
25	DLD	Male	5;6
26	COMPARATIVE	Male	5;6
27	COMPARATIVE	Male	5;6
28	DLD	Female	5;11
29	COMPARATIVE	Female	5;11
30	COMPARATIVE	Female	5;11
31	DLD	Male	6;7
32	COMPARATIVE	Male	6;7
33	COMPARATIVE	Female	6;7
34	DLD	Male	4;10
35	COMPARATIVE	Male	4;10
36	COMPARATIVE	Female	4;10
37	DLD	Male	9;11
38	COMPARATIVE	Male	9;11
39	COMPARATIVE	Male	9;11
40	DLD	Male	10;11
41	COMPARATIVE	Male	10;11
42	COMPARATIVE	Female	10;11

Note. DLD: Developmental Language Disorder; Comparative: typical language development.

Table 2 shows the comparison between the two groups in PWM, VSTM, and receptive vocabulary tests.

Table 2

Comparison between the study group (SG) and the comparative group (CG) in memory (phonological and visual) and vocabulary tests

	Mean		Standard deviation			
	SG	CG	SG	CG	*t*	*p*
NRT	43.57	67.00	10.99	11.04	-6.49	0.000
NRT (%)	56.64	86.98	11.83	8.48	-9.56	0.000
PMT	11.50	16.00	3.16	4.88	-3.13	0.003
PMT (%)	20.91	29.09	5.75	8.87	-3.13	0.003
PPVT-III	58.36	76.57	18.19	26.07	-2.34	0.024
PPVT-III (%)	30.41	42.47	9.46	17.61	-2.38	0.022

Note. NRT: Nonword Repetition Test; PMT: Pictorial Memory Test; PPVT-III: Peabody Picture Vocabulary Test; %: Percentage; *t*: *T-test* distribution value; *p*: significance value.

Table 3 shows the relative difference in the performance of both groups in PWM and VSTM tests. The performance of children with DLD in the picture test is proportionally better than in the non-word test. Relative difference between the tests was verified, taking into account that there may be a discrepancy in the complexity of application between procedures.

Table 3

The relative difference in the performance between the SG and CG

	Mean		% SG performance is inferior to CG
	SG	CG	
NRT	43.57	67.00	35%
PMT	11.50	16.00	28%

Note. NRT: Nonword Repetition Test; PMT: Pictorial Memory Test; %: Percentage.

Table 4 shows the correlation between memory and vocabulary tests in both groups.

Table 4

Correlation between memory and vocabulary tests in the SG and CG

	PPVT-III
NRT	*r* = 0.59
	p = 0.000
PMT	*r* = 0.55
	r = 0.000

Note. NRT: Nonword Repetition Test; PMT: Pictorial Memory Test; PPVT-III: Peabody Picture Vocabulary Test; *p*: significance value; *r*: Pearson correlation value.

Discussion

The term DLD is proposed to refer to cases of language disorder without previous biomedical condition, such as brain injury, acquired epileptic aphasia in childhood, certain neurodegenerative conditions, cerebral palsy, and oral language limitations associated with sensorineural hearing loss, as well as genetic conditions such as Down syndrome, autism spectrum disorder, and intellectual disability. Biological or environmental risk factors have been statistically associated with language impairment, but the causal relationship with the language problem is unclear or partial (Bishop et al., 2017). A systematic review found that commonly documented biological risk factors include a family history of language disorders and being male (Rudolph, 2017). In our study, 11 of 14 subjects with DLD were male (Table 1), and five had a family history of language or learning disorder, corroborating the risk in boys.

A fact of interest in the setting of communication, language, and speech impairments is that the male sex is a strong risk factor for the mentioned pathologies. In contrast, the female sex is a protective factor. This finding has been observed in countless studies and epidemiological reports. Every disorder regarding communication and language is more prevalent in men than in women. The results are consistent over many decades and across many regions and populations worldwide (Adani & Cepanec, 2019).

Children of the SG had a statistically significantly lower performance in comparison to those of the CG in the PWM test (Table 2). There was also a positive correlation between variables (Table 4) since worse performance in the non-word repetition test correlated with worse performance in the receptive vocabulary test. Other authors have found that the performance of children with DLD is lower than their peers' with TLD in tasks that evaluate PWM (Cáceres-Assenço et al., 2014; Hage et al., 2014; Acosta et al., 2019). Responsible for processing, storing, and manipulating verbal information, PWM maintains information stored in memory for a short period of time, and an articulation controller maintains information in memory through an internal recitation mechanism – subvocal repetition (Baddeley, 2006). To recall auditory information, individuals convert the acoustic information into a phonological

form that is used for subvocal repetition and for further storage in the long-term memory; in DLD, this encoding process shows a deficit (Jackson et al., 2020). This deficit would also be one of the factors that affect lexical acquisition.

One of the causes of limiting characteristic lexical-semantic knowledge in DLD is the deficit in the PWM, to the point of it being responsible for predicting vocabulary size (McGregor et al., 2002). There is evidence that PWM is a key component in the ability to learn new words (Baddeley, 2006; Jackson et al., 2016) and in the acquisition of language skills in general. The repetition of words that do not exist is a task that role-plays a situation in which one hears a new word, and, in this way, the repetition of non-words reflects the capacity of PWM to store unknown words. Children with DLD present more difficulty in learning new words than children with typical development, and this difficulty seems to be related to storing and manipulating verbal information.

Most studies that assess short-term memory in children with language impairments use tasks featuring auditory stimuli. Evaluation with visual stimuli is less common (Rueda & Sisto, 2007) because VSTM does not seem to interfere with the development of language.

The results of this work show that the pictorial memory of children with DLD was significantly lower (Table 2), but to a lesser extent (28%) when compared to the results of memory for the repetition of non-words (Table 3). There are studies that show that children with DLD have lower performance on VSTM tasks (Marton, 2008), however, there is also evidence that this ability is preserved. The results of Archibald and Gathercole (2006) show that children with DLD do not present deficits in visual memory, but in the short-term memory related to the verbal WM, indicating that deficits in short-term memory in children with DLD involve the verbal domain.

Through analysis of the ratio of the average performance between the groups (Table 3), we observed divergence in WM performances in the presentation of different forms of stimulus and that verbal stimuli were more difficult to store. Regarding pictorial stimuli, the physical characteristics of the scene are preserved. In contrast, in the verbal stimuli, these characteristics would have to be remembered, which is one of the explanations that one can remember more pictorial than verbal elements (Archibald, 2017).

Finally, the present study showed that there was a correlation between the performance in VSTM and vocabulary tasks (Table 4), suggesting that deficits in both PWM and VSTM have an impact on vocabulary acquisition. The hypothesis of this correlation is that despite WM having components with relatively distinct roles, it is a system that needs to work seamlessly as all its elements are responsible for cognitive tasks – among them, the acquisition of vocabulary.

In conclusion, this study showed that for both PWM and VSTM, children with DLD present a worse performance in comparison to their typical peers, with a performance difference dependent on the presentation of distinct forms of stimuli and with visual stimuli

more easily stored, even if the response was verbal. The positive correlation between memory and vocabulary tests suggests that both the phonological loop and visual memory are important for the processing of language, even if the phonological loop may have greater relevance. Anyway, careful attention should be paid to both verbal and visual WM in clinical practice, especially in those children with language impairments (Vugs et al., 2013).

Research that brings more clarification on how language deficits are processed in children with DLD would also be relevant for therapeutic planning. If sufficient time is spent on WM training, WM-related skills improve and the effects are also transferred to morphosyntactic language skills (Shahmahmood Toktam et al., 2018). WM assessments could provide important information about children's cognitive function over and above typical psychoeducational measures (Gray et al., 2019). For effective results, it is important to consider language and its functioning and the way that other skills, such as attention and memory, aid in the retention of information. The deficit in phonological and visual WM in children with DLD, in this study, indicates that intervention should combine visual and auditory activities, in order to facilitate the integration of information through stimuli received by more than one process pathway, thus improving language learning.

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