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Working memory in children: a precursor reading skill?

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Abstract

The reading process is considered complex and multifactorial, involves several cognitive abilities. Emerging writing, alphabetic knowledge, phonological awareness, vocabulary, rapid automatized naming and working memory (WM), are considered precursor skills of reading. The present study analysed the influence of different WM processes on the performance of the precursor skills of reading and how these processes impact on the outcome in pseudoword decoding. It was considered a sample of children from northeastern Brazil, literate in the pandemic period, aged between six and nine years, where Portuguese is the mother tongue and taught. The results of structural equation modelling indicated that different processes of verbal and visuospatial working memory impact, differently, on the performance of precursor abilities. Working memory is the fundamental skill that facilitates the integration of precursor abilities and impacts on the efficiency of the pseudoword decoding process.
Keywords: working memory; reading; neuropsychology; neuroscience; education

Resumo

Memória de trabalho em crianças: uma habilidade precursora de leitura? O processo de leitura é considerado complexo e multifatorial, envolve diversas habilidades cognitivas. Escrita emergente, conhecimento alfabético, consciência fonológica, vocabulário, nomeação automática rápida e memória de trabalho (WM), são consideradas habilidades precursoras da leitura. O presente estudo analisou a influência dos diferentes processos de WM no desempenho das habilidades precursoras da leitura e como estes processos impactam no desfecho em decodificação de pseudopalavras. Foi considerada uma amostra de crianças do nordeste brasileiro, alfabetizadas no período pandêmico, com idade entre seis e nove anos, onde o português é a língua materna e ensinada. Os resultados da modelagem por equações estruturais indicaram que diferentes processos de memória de trabalho verbal e visuoespacial impactam, de forma distinta, no desempenho das habilidades precursoras. A memória de trabalho é a habilidade fundamental que facilita a integração das habilidades precursoras e impacta na eficiência do processo de decodificação de pseudopalavras.
Palavras-chave: memória de trabalho; leitura; neuropsicologia; neurociência; educação

Resumen

Memoria de trabajo en niños: ¿una habilidad de lectura precursora? La escritura emergente, el conocimiento alfabético, la conciencia fonológica, el vocabulario, la nomenclatura automática rápida y la memoria de trabajo (MT), se consideran habilidades precursoras de la lectura. El estudio analizó la influencia de diferentes procesos de MT en el rendimiento de las habilidades precursoras de lectura y cómo estos impactan en el resultado en la decodificación de pseudopalabras. Se consideró una muestra de niños del noreste de Brasil, alfabetizados en el período de la pandemia, con edades comprendidas entre seis y nueve años, donde el portugués es la lengua materna y se enseña. Los resultados del modelado de ecuaciones estructurales indicaron que diferentes procesos de memoria de trabajo verbal y visuoespacial impactan, de manera diferente, en el desempeño de las habilidades precursoras. La memoria de trabajo es la habilidad fundamental que facilita la integración de las habilidades precursoras e impacta en la eficiencia del proceso de decodificación de pseudopalabras.
Palabras clave: memoria de trabajo; lectura; neuropsicología; neurociencia; educación

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Introduction

Reading is a cognitive skill acquired by humans that facilitates its adaptation in the environment in which it lives. It is through it that there is an expansion in the forms of communication between members of the same group. In addition, reading overcomes temporal barriers, so that information can be read by several generations (for example, cave paintings or scrolls).

The variables that influence the development of reading cannot be summarized to the educational context, because the familiar, cultural, social, and cognitive characteristics also contribute to its advancement (Monteiro & Martins, 2020). Thus, success and impairment in reading acquisition can be caused by several factors and its impact can favour the emergence of complex social problems, such as illiteracy. For this, it is also fundamental to evaluate this skill, to build intervention protocols that reduce the impact of these problems (Albuquerque & Martins, 2022).

For children, this skill is essential for academic success, since it is through reading that the child understands the information of other curricular components. In addition, the initial experiences of reading acquisition are decisive on how the individual will see this activity throughout his life (van Bergen et al., 2021). It is emphasized that the term "reading" is complex and can be divided into several competences. One of the steps to be achieved by the child during the acquisition of reading is decoding.

Decoding refers to the individual's ability to transform written language into spoken language, with precision and fluency (Gough & Tunmer, 1986). During the decoding process, the developing reader uses two types of routes for reading. At first, this is seen before the phonological route, responsible for decoding the word, in grapheme-phoneme, to later access the lexicon and understand what is written. With the improvement of this route, the reader will use another route: the lexical route, where he observes the word and already accesses the lexicon for the spoken reproduction of what is written (Georgiou et al., 2021; Hung, 2021; Lima et al., 2020; Rezaei & Mousanezhad Jeddi, 2020). One of the cognitive skills that relates to the earliest stage of decoding is working memory (WM, Peng et al., 2018).

Work memory (WM) is characterized by storing and manipulating information, continuously (Cowan, 2017) and consciously (Swanson, 2017). The ability to manipulate conscious information is used to solve complex problems and coordinate tools aimed at a goal (Adams et al., 2018). Regarding decoding, it is observed that the different domains of WM provide specific contributions to its success (Pham & Hasson, 2014). In children, these domains are investigated in phonological aspects (verbal WM), where the focus is the use of auditory and visuospatial information (visuospatial WM), with the analysis for visual movements and spatial orientation.

The scientific literature confirms the importance of WM with the ability to recognize words and read comprehension (Slomowitz et al., 2021), in addition to the importance for the speed of articulation (da Silva et al., 2020) and for the phonological sensitivity of pre-children students (Pazeto et al., 2017), as well as a predictive variable for reading, more than for mathematics (Mammarella et al., 2018b; Swanson, 2017). Students with better performance in verbal WM can recover the sounds of the letters and combine them in decoding (Lima et al., 2020), in addition to maintaining a greater amount of phonological information for interpretation and understanding (Hung, 2021).

WM can manipulate information from passive and active processes, as addressed by the studies of Cornoldi and Vecchi (2003) and Mammarella et al (2008), which already reported WM from this perspective. In passive mode, the information reaches the WM and does not require manipulation or transformation of the content. This can be observed in the digit extension task in direct order, when the evaluator says a sequence of numbers and the subject must repeat in the same order. In contrast, the active process corresponds to the mechanism of information manipulation and/or content transformation, from visual to verbal, for example, also observed in the task of repeating a sequence of digits in reverse order (Alloway et al., 2017; Cockcroft & Milligan, 2019; Kuhn, 2016; Mammarella et al., 2008; Vugs et al., 2016).

For these reasons, WM is considered one of the precursor skills of reading. In addition to this, one can specify: alphabetic knowledge, emergent writing, vocabulary, phonological awareness, and rapid automatized naming. Together, these skills facilitate the process of decoding and subsequent success in reading (Lima et al., 2020), and make reading reach its peak of automaticity and thus facilitate fluency and understanding of what is being read by the individual (Castro & Barrera, 2019). In studies with the precursor skills of reading impacting the decoding of words and pseudowords, WM presents a special participation in the models. Table 01systematizes the relationship of WM with the other precursor abilities.

Table 1: *Resume of the Theoretical Relationships of Reading Predictor Skills with Working Memory*

Skill	Definition	Importance for Reading	Relationship to WM	How can WM contribute?
Alphabetic Knowledge	Know the alphabetic system, the sound of each letter and which form their own name (Monteiro & Martins, 2020).	It signals the individual's competence in differentiating visual features (Dehaene, 2013).	Association with children who knew the Portuguese (Pazeto et al., 2017) and Polish (Wiejak et al., 2017) alphabet.	The child maintains the visual information of the letter in consciousness while reading the words.
Emergent Writing	Writing the letters of the alphabet, one's own name, and simple words spontaneously (Castro & Barrera, 2019).	It promotes advances in word reading and orthographic lexicon formation (Monteiro, & Martins, 2020).	Association with verbal and visuospatial WM measures (Castro & Barrera, 2019; Côrrea et al., 2018; Pazeto et al., 2017).	Remember the phonological, visual and spatial characteristics of letters.
Vocabulary	Repertoire of words archived in the lexicon of the individual (Bandini et al., 2017).	It facilitates the speed at which the child can read familiar words (Peng et al., 2018).	Associated with verbal WM measures (Pazeto et al., 2017; Peng et al., 2018)sílabas ou palavras isoladas. Evidências sugerem que sua aquisição é determinante para o posterior sucesso acadêmico ao longo da educação básica, reiterando a importância da avaliação precoce. Considerando a escassez de instrumentos de avaliação nacionais, o objetivo deste estudo é apresentar e disponibilizar o Teste de Leitura e Escrita (TLE.	Ability to quickly access phonological information in long-term memory.
Phonological Consciousness	The ability to understand the phonological structure of words and manipulate their phonemes (Castro & Barrera, 2019).	It allows children to identify phonemes of spoken language and transform them into written words (Westerveld et al., 2018).	Relationship with verbal WM. Favors phonological manipulation (Peng et al., & 2018)	Ability to manipulate phonological information. Awareness of phonemes is a linguistic skill, but conscious manipulation is not.
Rapid Automatized Naming	Speed with which it accesses the lexicon (da Silva et al., 2020)	Differentiates between children with and without specific delays in word reading (da Silva et al., 2020; Lima et al., 2020; Rowe et al., 2019) in addition to children with and without risk for dyslexia (Santos & Capellini, 2020).	There is a relationship of the results with verbal WM indices assessed by digit length in reverse order (da Silva et al., 2020).	Ability to access information in long-term memory quickly and efficiently. Able to coordinate the action of this ability.

Questions and Hypotheses of Research

The WM is related to the precursor abilities of reading, with higher indexes in their relation to verbal WM (Peng et al, 2018; Giofrè et al, 2018). Therefore, it is observed that WM should be considered as a workspace, where information is maintained and manipulated actively and passively (Cockcroft & Milligan, 2019; Alloway et al., 2017; Kuhn, 2016; Vugs et al., 2016; Mammarella et al., 2008). Previous research reports the importance of WM for reading as one of its precursor abilities. However, the analyses go through for the use of simple correlations and analysis of outcome based on theoretical models of WM that do not favor its complete capacity.

A limitation of empirical studies is the use of a single task to summarize the entire WM capacity (most of the time, repeating a sequence of digits in reverse

order). However, it is questionable whether the result really includes MT as a whole or just a part of its capacity. For example, a child may have difficulties with the phonological aspects of WM but be efficient in the visual or spatial domain. If this were to occur, it would not benefit from the results of research that used only a verbal task as a measure of WM (Peng et al., 2018; Wilhelm, Hildebrandt, & Oberauer, 2013).

The focus of research in this area is only verbal WM makes knowledge limited, considering that processes for visuospatial content are also fundamental and important for reading (Peng et al., 2018). Thus, it is not clear about which capacity of WM is important for reading, since it is observed that only a part of its totality is investigated. The present study advances in the understanding that WM is a skill cognitive ability, capable of acting in active and passive processes of maintenance and manipulation of information, so that all contents will be valued in the analyses, not only the verbal WM. In this sense, the following research questions were studied:

Does working memory influence the performance of precursor reading skills?

The relationship between working memory and precursor skills impacts decoding performance in the children who experienced emergency remote learning?

To answer these questions, structural equation analysis was performed. Regarding the first research question, it was expected that WM would contribute to the performance of precursor skills, not being as just another skill that would influence the process of decoding pseudowords, that is, it would be used as the very environment from which they would integrate the precursor skills of reading. This would be supported by the way WM relates to the precursor skills and the decoding process (Lima et al., 2020; Pazeto et al., 2017; Peng et al., 2018), based on the model where precursor skills would serve as mediating variables of the relationship between WM and decoding.

Finally, for the second question, the hypothesis was that this relationship between WM impacting the precursor abilities of reading, would influence the performance of decoding in pseudowords. It was expected that success in decoding would be dependent on how WM, in its different processes, would contribute to performance in precursor abilities. This finding is already discussed in the scientific literature, for recognizing that WM contributes specifically to the reading process, not only in understanding (Morris & Lonigan, 2022), but fundamental to the acquisition of reading (Lima et al., 2020; Peng et al., 2018; Swanson, 2017).

Materials and method

Participants

A total of 100 children (53 girls) from the cities of Bayeux, Santa Rita and João Pessoa, in the state of Paraíba, Northeast region of Brazil, participated in the study. Half of them were enrolled in public schools. Data from children who had a previous diagnosis of a neurodevelopmental disorder or alteration, a history of grade repetition before the pandemic period, as well as uncorrected visual and auditory deficits (based on parents' responses) were excluded. Among the participants, 34 were in the 1st year of elementary school, 37 in the 2nd year and 29 in the 3rd year. The group was chosen because it represents the school years in which formal teaching of reading in Brazilian Portuguese takes place, which had experienced the closure of schools and, soon after, emergency remote teaching. In the emergency remote education system in these cities, the online study period ranged from 10 to 18 months (the sample was evaluated at the end of this period).

Instruments

The evaluation battery brought together different research instruments, already validated and in use in the Brazilian context, to achieve the specific objectives of the present study. These will be presented based on the characterization of the latent variables under investigation. The children's information was evaluated by school documentation.

Working Memory:

Computerized Working Memory Task for Children (TIMTraC; Cordeiro et al., 2019)a TIMTRaC foi informatizada com a utilização do GameMaker e sua adequação foi avaliada qualitativamente a partir da aplicação com um pequeno grupo amostral (N=20:

The task assesses visuospatial WM in two blocks of activities, which require performance in content maintenance (passive WM) and categorization (active WM) skills. In Block 1, the child sees a sequence of animal drawings and must reproduce by selecting stimuli from a group of distractors. In Block 2, the child observes drawings of animals and means of transportation and must categorize on two levels (context and environment). Performance is observed by partial scores, where the recalled stimuli, of each specific sequence (minimum=0; maximum=35), in each block are counted. At the end, the task provides the overall score of the child's performance, with partial points (minimum=0; maximum=70). Both blocks and the overall score

showed satisfactory internal consistency indices in this study (α = 0.86).

Caminho de João (CJ; The Pathway Span task, inspired in Mamarella et al, 2008; Cornoldi et al, 1995):

The task proposes to evaluate the visuospatial WM from the mental manipulation of a figure within a matrix (active visuospatial WM). The evaluator expresses statements where the figure will move in the matrix and the child should indicate where it would end. The difficulty of the task involves the pattern of the matrix (2x2 to 6x6) and the number of commands provided by the evaluator (from one to ten commands). The score obtained in the task presents a satisfactory index of internal consistency, identified in the present study (α=0.76).

Digit Extension and Pseudowords - Children's Brief Neuropsychological Evaluation (NEUPSILIN-Inf; Salles et al., 2016):

The subtest of digit repetition in direct order (DOD), inverse (DOI) and pseudoword extension (SPP) are considered as evaluation measures for verbal working memory (Tomaz et al., 2021). For DOD (passive verbal WM), the participant listened to a sequence of numbers and repeated them in the same order. Regarding PPS (passive verbal WM), the participant heard a sequence of pseudowords and should repeat the sequence in the same order. Finally, in DOI (active verbal WM), the participant heard a sequence of digits and repeated them in the opposite order. The difficulty was in the number of stimuli signalled by the evaluator. In the original study, the reliability of the task was considered by the test-retest relationship ($r=0.632$; $p<0.001$ for DOD; $r=0.681$; $p<0.001$ for SPP; $r=0.568$; $p<0.001$ for DOI).

Precursors Skills for Reading:

Instrument for Assessment of Literacy Precursor Skills (Pré-Alfa; Pereira, 2021; Pereira et al., in press):

The instrument was used as a resource of easy application with children of the investigated age group. From this, we used the subtests of alphabetic knowledge (naming letters and producing the sound of these letters), emergent writing (writing letters, own name, and spontaneous writing), phonological awareness (alliteration, phonemic subtraction and syllabic manipulation) and vocabulary (name figures). The description of the tasks and evidence of validity are observed in Pereira (2021).

Rapid Automatized Naming (NAR, built by authors and inspired by Wolf & Denckla, 2005):

The task was built for the participant to verbalize, as soon as possible, the name of the stimuli presented on the computer screen (colours, figures, letters, and numbers). In any category 50 stimuli will be presented and the score of the task is counted by the time spent in each category. The beginning of the time count is from the first word spoken by the participant and the ending is recorded with the last word verbalized.

Decoding:

Evaluation of Reading Isolated Words and Pseudowords (LPI; Salles et al., 2017):

This task evaluates the reading of isolated words and pseudowords. For optimization of the application time, it was observed only the performance of reading pseudowords (LPP), because this is a good measure of decoding, besides cancelling the use of the lexical route by already reading children. Psychometric data are observed in the validation study Salles et al. (2013).

Ethical and collection procedures

The study was approved by the Ethics Committee under the number CAAE: 53218521.4.0000.5188. At the time of collection, the guardians of the children received the Informed Consent Form (TCLE) and only children who had the signed term participated. These performed the activity in a quiet space of the school. The tasks used in the study were computerized, so the children were presented to the materials (computer and mouse). On the side, the evaluators followed the application, answered the doubts that could arise during the application of the tasks and recorded the answers. To avoid the impact of fatigue/demotivation in the performance of tasks, the counterbalancing of tasks was performed. The application lasted up to two hours, requiring up to two meetings with the child.

Procedures for the analysis of data

The data homoscedasticity criterion was not met in the sample, assessed by the Kolmogorov-Smirnov test ($p<0.05$), therefore, non-parametric statistics were used. Spearman's correlations were initially performed to investigate the relationship between the study variables. After verifying the relationships, we sought to analyse, through structural equation modelling, whether the different WM processes, as described in the continuity model, would impact on the precursor reading skills and, therefore, in the decoding process. The analysis was implemented using the Robust Diagonally Weighted Least Squares (RDWLS) estimation method, suitable for categorical data that do not follow normality (DiStefano & Morgan, 2014; Li, 2016).

The adjustment indexes used were: χ^2; χ^2/gl Comparative Fit Index (CFI); Tucker-Lewis Index (TLI); Standardized Root Mean Residual (SRMR) and Root Mean Square Error of Approximation (RMSEA). Values of χ^2 should not be significant; ratio χ^2/gl should be < 5, or preferably < 3; CFI and TLI values should be > 0.90 and preferably above 0.95; RMSEA values should be < 0.08 or preferably < 0.06 with confidence interval (upper limit) < 0.10 (Brown, 2015). The analyses were performed using the JASP software (Version 0.16.3; JASP Team, 2022).

Results

Initially we sought to evaluate the relationships between the variables of WM and the precursor skills of reading. As shown in Table 2, verbal WM measures are more related to the precursor reading abilities than to visuospatial measurements, with intensities ranging from weak to moderate. This result highlights the extension of digits in reverse order that was related to all precursor reading skills investigated.

Table 2: *Correlation Analyses Among the Study Measures*

Tasks	B1	B2	CJ	DOD	SPP	DOI
Name writing	0.07	0.06	-0.02	0.14	0.17	**0.22***
Writing of Letters	0.08	0.07	0.12	0.13	0.24*	0.32**
Spontaneous Writing	0.10	0.05	**0.20***	**0.27****	0.14	**0.39****
Letter Naming	0.12	-0.05	0.15	**0.22***	**0.20***	**0.37****
Sound of Letters Naming	**0.20***	0.13	0.03	0.17	**0.43****	**0.38****
Aliteration	0.13	**-0.21***	0.13	**0.36****	**0.24***	**0.40****
Syllabic Manipulation - Addition	-0.01	-0.07	-0.03	**0.28****	0.04	**0.30****
Syllabic Manipulation - Subtraction	0.06	0.02	-0.02	0.13	0.01	**0.35****
Vocabulary	**.23***	0.08	-0.09	**0.23***	0.18	**0.34****
NAR_Collors	**-0.20***	0.04	-0.10	**-0.20***	-0.10	**-0.43****
NAR_Figure	-0.20*	-0.19	0.08	-0.03	**-0.35****	**-0.21***
NAR_Letters	-0.13	0.07	**-0.21***	**-0.28****	-0.19	**-0.37****
NAR_Numbers	-0.14	-0.10	-0.15	**-0.22***	-0.09	**-0.36****
Decoding	**0.27****	-0.03	0.15	**0.35****	**0.27****	**0.55****

Note. **p* < 0,05; ***p*<0,01. B1 = Block 01 of the Computerized Working Memory Task for Children; B2 = Block 02 of the Computerized Working Memory Task for Children; CJ = "*Caminho do João*"; DOD = Digit repetition in direct order; SPP = Pseudoword extension; DOI = Digit repetition in inverse order; NAR = Rapid automatized naming.

The relationships involving visuospatial measurements and predictive reading skills demonstrate that CJ is significantly positively related to spontaneous writing (p<0.05). For this last ability, there is also a relationship with DOI, of greater intensity (r = 0.39; p <0.01). However, the r-to-z Fisher transformation test indicated difference is not significant (z = 1.44; p = 0.07) and measurements, verbal and visuospatial, do not differ in the shared data variance. This equivalence is repeated comparing relationship strengths of verbal and visuospatial measures with the predictor skills of reading.

Block 01 of the TIMTraC was positively related to letter-sound naming and vocabulary (p < 0.05). The same measure correlated significantly negatively with NAR of colours and figures, demonstrating that the better the performance in the passive visuospatial WM skill, the less time was spent for naming. This observation is also observed between CJ and NAR of letters.

To perform a more robust analysis of the relationships among the variables, structural equation modelling was performed using the indicators described above. For this, to establish the appropriate level

of parsimony among the data, the measures were associated with each other to form specific factors, namely: emergent writing, alphabetic knowledge, phonological awareness, and rapid automatized naming. The factorization indices can be seen in Table 3 and the model fit indices in Table 4.

Table 3: *Factor Loads for Latent Variables*

Latent Variable	Indicator	Factorial Load	Standard Error	value-*p*
Emerging writing	Name writing	0.46	0.10	0.02
	Writing of Letters	0.78	1.00	<0.001
	Spontaneous Writing	0.51	1.14	<0.001
Alphabetic Knowledge	Letter Naming	0.54	0.00	<0.001
	Production of Sound of Letters	0.61	0.54	<0.001
Phonological Consciousness	Alliteration	0.39	0.12	<0.001
	Syllabic Manipulation - Addition	0.92	0.12	<0.001
	Syllabic Manipulation - Subtraction	0.75	0.11	<0.001
Rapid Automatized Naming	Colours	0.81	1.12	<0.001
	Figure	0.81	1.27	<0.001
	Letters	0.82	1.55	<0.001
	Numbers	0.87	1.26	<0.001
Verbal Active WM	Items of the DOI*	0.28 – 0.96	0.06 – 0.13	<0.001 – 0.002
Verbal Passive WM	Items of the DOD and SPP*	0.21 – 0.94	0.09 – 0.15	<0.01 – 0.05
Visuospatial Active WM	Items of the B1*	0.28 – 0.94	0.08 – 0.19	<0.001 – 0.01
Visuospatial Passive WM	Items of the B2*	0.42 – 1.68	0.08 – 0.17	<0.001

Note. *The indicators used for working memory measurements were task items. Unlike the reading variables, which used the final results. The values described are the ranges in this case. The task "*Caminho do João*" was removed because it did not present satisfactory values.

Table 4: *Adjustment Indexes that Confirm the Formation of Factors*

								IC 90% RMSEA	
Predictive Skills of Reading	χ^2	gl	χ^2/gl	CFI	TLI	SRMR	RMSEA	Lower Limit	Upper Limit
Emerging writing	32.15	3	10.71	1.00	1.00	2.434e-8	0.00	0.00	0.00
Alphabetic Knowledge	0.45	5	0.09	1.00	1.10	0.02	0.00	0.00	0.00
Phonological Consciousness	4.98	2	2.49	0.98	0.93	0.10	0.12	0.00	0.26
Rapid Automatized Naming	1.23	2	0.61	1.00	1.01	0.04	0.00	0.00	0.17
Verbal Active WM	295.71	28	10.56	0.90	0.86	0.07	0.12	0.07	0.16
Verbal Passive WM	260.24	66	3.94	0.65	0.58	0.10	0.11	0.08	0.13
Visuospatial Active WM	287.60	21	13.69	0.94	0.90	0.05	0.11	0.06	0.16
Visuospatial Passive WM	114.37	21	5.45	0.95	0.94	0.05	0.05	0.00	0.12

Subsequently, structural equation modelling was implemented to investigate the extent to which active and passive WM processing impacted precursor reading skills and how they impacted decoding. The results of the model are presented in Figure 01.

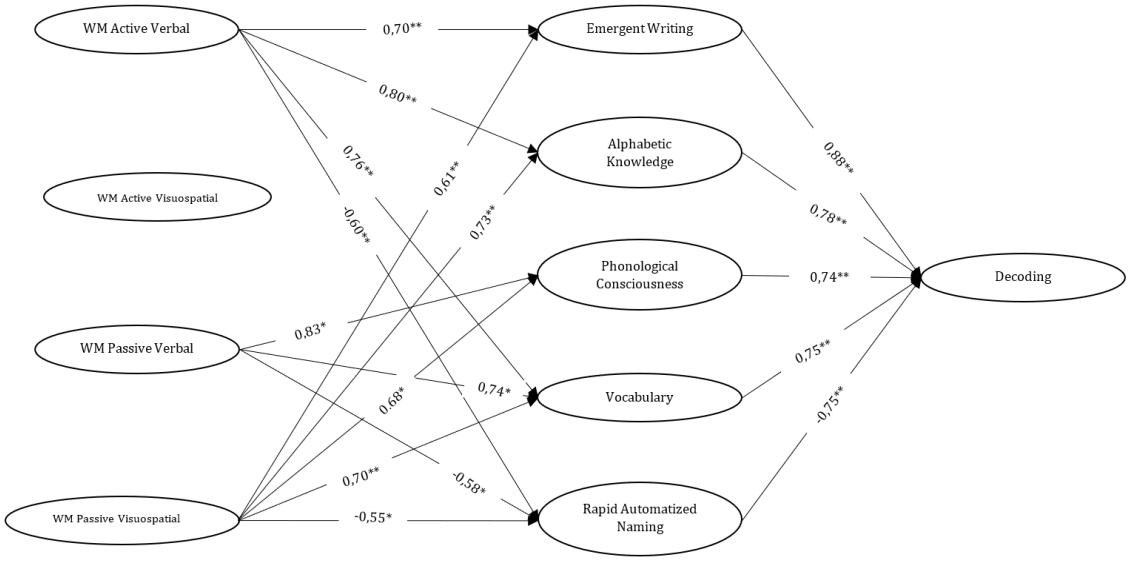

Figure 1: *Structural Equation Model of the Relationships Between Active and Passive WM Processes with Reading Predictor Skills.*
*Note. *p < 0.05; **p<0.01.* The figure is representational and, for reasons of parsimony, the items that make up each dimension will not be presented. Relationships that were not significant were also excluded from the figure.

The model becomes plausible based on the fit indices (χ^2 (1510) = 1510.82; χ^2/gl = 1; CFI = 1.00; TLI = 1.00; RMSEA = 0.002; SRMR = 0.09). As can be seen, the active processing of verbal contents and passive processing of both verbal and visuospatial contents present significant outcomes in the predictive abilities of reading. These, in turn, impact decoding performance. The prediction in the relationship of active verbal WM with phonological awareness was not significant (β = 0.71; p = 0.37), for this, the contribution was more specific by passive verbal WM, which also influenced the outcome of vocabulary and rapid naming. Active visuospatial WM also did not impact the outcome of any predictive ability. On the other hand, passive visuospatial WM significantly impacted the outcomes of all investigated predictive reading skills.

Discussion

In the present study, we sought to investigate how the different WM processes influence the predictive abilities of reading and the decoding process in a sample of children from the Brazilian northeast, literate in the pandemic period. The results of structural equation modelling indicated that different WM processes impact, in a distinct way, the performance of children in predictive reading skills. The results agree with the literature of the area, by the understanding that WM plays a fundamental role in the development of reading (Giofrè et al, 2018; Kyttälä et al, 2019; Peng et al., 2018; Swanson, 2017).

For the public that is acquiring the ability to read, it is already recognized that greater effort is required from the WM (Zhang & Josh, 2020), so that in children with good reading performance, this analysis reaches zero (Rezaei & Mousanezhad Jeddi, 2020). Among the intervention protocols in reading that associate it with WM stimulation, these are shown to be more effective, even when compared to those that do not privilege this skill (Carretti et al., 2014; Fuchs et al., 2018).

As already pointed out by review studies (Peng et al., 2018; Swanson, 2017), there is a difference in the contribution of processing by WM about verbal and visuospatial content, where the former has the highest intensity in the relationship (Hjetland et al., 2019; Peng et al, 2018). The present study confirms this consideration and can be justified by the way in which the predictor skills are constituted, as most draw on the use of phonological codes. However, this does not nullify the influence of relations with visuospatial content because, even with higher indices, the difference in relation is not shown to be statistically significant.

Active verbal WM contributed significantly to emergent writing, alphabetic knowledge, vocabulary, and rapid automatized naming. The factor is formed by the task of extending digits in reverse order. This process requires active manipulation and is like the process of accessing the lexicon and relating phonemes to form

a word, thus issuing verbal information. This process can also be observed in vocabulary (Peng et al, 2018), in rapid naming (Labanienè, 2020) and in alphabetic knowledge (Pazeto et al, 2017).

What is not in agreement with the literature concerns the non-significant relationship of active verbal WM with phonological awareness (Kudo et al., 2015; Peng et al., 2018). The two skills share phoneme manipulation, however, in phonological awareness, the child needs teaching about recognizing that graphemes are endowed with sound information (Mohamed et al., 2019; Westerveld et al, 2018). Another study with the Brazilian population also showed this association profile (Lima et al., 2020). Two specific hypotheses are found: the first concerns the failure to learn the sound of letters, which may influence task performance (Landim, & Flores, 2018) and impact the relationship; and the second hypothesis concerns the fact that phonological awareness requires more of the passive maintenance of information, than the active one.

For passive verbal WM, the child does not need to manipulate the information and recoding consists of responding with the same demand in which the subject captured the information (Mammarella et al., 2008). This was the process that was related to phonological awareness, vocabulary, and rapid automatized naming in this study. The result suggests that the faster and more accurately a child can retain phonological information, the higher the quality of the information, which will result in a greater predisposition to maintain verbal fluency and comprehension of the text read (Hung, 2021; Lima et al., 2020). These findings need further research in the area, with the breadth of tasks that measure passive and active verbal WM.

About visuospatial WM, studies on this process are scarcer (Mammarella et al., 2018). Of those that set out to assess its relationship with reading, they favour the understanding that the relationship is of low intensity (Peng et al., 2018), although some studies indicate that it is predictive of reading, more so than active verbal WM tasks (Lima et al., 2020). The pattern of relationship changes as native languages are observed. There is a greater impact of visuospatial WM for Chinese children (Pan & Lin, 2020), than for Brazilian children (Lima et al., 2020). In addition, studies with visuospatial WM are more related to reading comprehension (Hung, 2021) and math performance (Mammarella et al., 2018a).

In the present study, passive visuospatial processing correlated better with all reading predictor abilities, more so than active visuospatial WM, which correlated significantly with none. This data offers the opportunity to discuss the importance of visuospatial WM for the early years of formal schooling, where the process of reading acquisition is under consolidation and is shown to be dependent on all WM processes to constitute itself.

Thus, it is hypothesized that passive visuospatial WM is important for the process of acquisition of reading because it should be used in the identification of graphemes and transformation into phonemes. The faster this process occurs, the easier the decoding process is and the faster the understanding of what is being read. Therefore, the use of active manipulation is not observed, because after the grapheme-phoneme transformation, phonological resources will take over the work of maintaining and manipulating information so that the child verbalizes verbal information. More studies need to clarify this hypothesis, although the importance of visuospatial WM for reading is already evidenced (Giofrè et al, 2018; Kyttälä et al., 2019; Pan & Lin, 2020; Pham, & Hasson, 2014; Peng et al., 2013; Wiejak et al., 2017).

It is important to conclude the discussion of the findings by indicating that this study had some limitations that went beyond the researchers' control. The sample is detailed in children whose literacy occurred in the pandemic period, where emergency remote education was not well established. The schools were unprepared for the teaching of reading skills online and in the return to face-to-face, it was noticed how the pedagogical structure presented failures in coordinating the new normal. Data from this study should be limited to this condition.

Final Considerations

WM proves to be one of the executive functions that best assist the adaptation of the child in the environment in which he lives, especially for his school experience (Gonçalves et al., 2017). With the intrinsic relationship with language and its contribution to the process of acquisition of reading (Pazeto et al., 2017; Swanson, 2017), the outcomes that WM influences need to be clarified and the studies should be expanded, in the perspective that when the individual can read, it can change the environment in which it lives.

The study was designed to assess how different WM measures were related to predictive reading skills

in a sample of children in northeastern Brazil, literate in the COVID-19 pandemic. In addition to being in the early years of formal schooling and reading development, the results indicate that different WM processes have different outcomes in the performance of these skills and therefore in the impact of the decoding of pseudowords. The focus of this study is on the distinct contribution of these different processes of maintenance and manipulation of information, with emphasis on the maintenance of visuospatial information for success in the performance of the child who is learning to read.

From this perspective, the present study advances this understanding by understanding that WM is not only one of the predictive skills, but the processing environment where predictive reading skills will integrate and assist the decoding process. The better children are at retaining visuospatial information and can keep this information conscious, the more access to information will be observed and the faster the individual performs grapheme-phoneme transformation.

The results here indicate how important and necessary the WM is for the adaptation of children in a limited period as the emergency remote education. In addition to these considerations, the results indicate how the intervention needs to be carried out, so that it is not only the discourse that there was a negative impact of the pandemic on schooling. It is necessary that the manuals value the basic cognitive processes, as WM, and that this process be taught to professionals who deal with this public. In addition, it is of paramount importance that rehabilitation and/or early intervention activities value other WM processes, not only with verbal content, as both impact decoding performance.

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