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NEUROPSYCHOPEDAGOGICAL PERSPECTIVE: RELATIONSHIPS BETWEEN WORKING MEMORY AND MOTOR, INHIBITORY CONTROL, AND LINGUISTIC DEVELOPMENT IN ELEMENTARY SCHOOL

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Abstract:
Working memory plays a pivotal role in cognitive functioning, serving as a dynamic interface for processing and integrating information across various domains. It is crucial for executing complex tasks such as reading comprehension, mathematical problem-solving, and logical reasoning. This study investigates the relationship between working memory and motor skills, inhibitory control, and language abilities in elementary school students, highlighting the role of specific assessment instruments in this analysis. The research involved 1107 students, aged 7 to 10 years, from public schools in Joinville, Brazil. Working memory was evaluated using the Neuropsychopedagogical Screening Scale for Working Memory (NSSWM), which comprises 23 items that assess the temporary storage and processing of information needed for tasks such as language comprehension, arithmetic, and problem-solving. Motor skills were assessed using the Neuropsychopedagogical Screening for Children's Motor Development, a 7-item scale focusing on motor coordination, fine motor control, and organizational skills during school activities. Inhibitory control was measured with the Child Inhibitory Control Screening Scale (CICS), which includes 18 scenarios that evaluate inhibitory responses, planning, and impulsivity. Phonological skills were assessed using the Screening Scale for Phonological Skills (SSPS), which measures the ability to recognize formal language

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characteristics through 17 items. Lastly, reading and writing skills were evaluated using the Children's Reading and Writing Screening Scale (CRWSS), a 16-item scale designed to identify potential difficulties in acquiring these skills in a school setting. The results revealed significant correlations between working memory and other cognitive domains, with motor skills exhibiting the strongest association (r=0.916, p=0.012). Additionally, inhibitory control (r=0.732, p=0.028) and phonological awareness (r=0.815, p=0.034) showed strong correlations with working memory, indicating that students with better-developed skills in these areas tend to perform better in working memory tasks, which, in turn, positively impacts their academic performance. The study underscores the importance of early neuropsychopedagogical interventions that address both cognitive and motor development. By employing specific, targeted assessment instruments, educators and mental health professionals can better identify students at risk of academic difficulties and implement effective strategies to enhance their cognitive and behavioral development, ultimately fostering a more supportive and inclusive learning environment.

Keywords: children; working memory; motor skills; inhibitory control; language skills

1. Introduction

Working memory, also known as operational memory, is a fundamental component of the human cognitive system, playing a critical role in the ability to sustain and manipulate temporary information necessary for executing complex cognitive tasks. This memory functions as a dynamic interface, processing and integrating information from different cognitive sources, allowing individuals to perform a variety of intellectual activities, from simple tasks like mental arithmetic to more complex ones such as reading comprehension and problem-solving (Baddeley, 2000; Cowan, 2017). Baddeley's classical theory proposes that working memory consists of several interconnected components, including the phonological loop, the visuospatial sketchpad, the episodic buffer, and the central executive, which together facilitate real-time information processing and manipulation (Oberauer, 2019; Cowan *et al.*, 2024).

The role of working memory in academic performance has been extensively studied, as this memory is essential for success in a wide range of school activities. It enables students to retain and manipulate information while performing tasks such as following complex instructions, solving mathematical problems, and understanding long texts. Moreover, working memory is crucial for active learning, where students need to integrate new information with pre-existing knowledge (Gathercole *et al.*, 2004; Peng *et al.*, 2019). Recent literature has reinforced the idea that the effectiveness of this memory can predict school success in various subjects, acting as a critical mediator between acquired knowledge and the application of that knowledge in evaluation and performance contexts (Peng *et al.*, 2019).

Therefore, working memory is not only a facilitator of academic performance but also a central cognitive function that contributes to broader cognitive and behavioral development. Its influence extends beyond the school environment, also affecting the emotional and social development of children, as skills such as inhibitory control and motor coordination are fundamental for healthy social interactions and the execution of daily tasks (Diamond & Ling, 2020; Vieira *et al.*, 2021; Sankalaite *et al.*, 2023). Understanding the importance of working memory in the overall development of children and adolescents allows educators and mental health professionals to identify cognitive difficulties early and implement effective interventions that can improve both academic performance and the general well-being of children (Blair & Raver, 2015). Based on these observations, this study aims to investigate the possible relationship between the level of skills related to working memory and the development of motor skills, inhibitory control, and linguistic abilities in elementary school students.

2. Literature Review

2.1 Working Memory and Motor Development

Motor competence is defined as the ability to perform a variety of motor skills that require coordination and motor control, primarily encompassing fundamental locomotor skills (such as running and jumping) and object control skills (such as catching and throwing) (Lubans *et al.*, 2010). These competences begin to develop in the early years of life and are refined over time, evolving into context-specific and sport-specific skills (Robinson *et al.*, 2015). Good motor competence is considered essential for the physical, social, and psychological development of children, as well as serving as a foundation for an active lifestyle (Flôres *et al.*, 2019).

Early childhood is a period during which children's physical, motor, and cognitive skills develop rapidly. Implementing well-structured and carefully planned Physical Education programs is essential for promoting children's physical, social, and emotional well-being, as well as encouraging regular physical exercise (Niemistö *et al.*, 2019). Although many studies have separately analyzed the impact of physical activity on motor competence or working memory, there is still limited evidence regarding the effects of specifically designed interventions aimed at improving both motor competence and working memory. Additionally, the relationship between motor competence and working memory remains poorly understood (Arufe Giráldez *et al.*, 2021).

Motor development, although often underestimated in its connection to academic performance, is closely linked with working memory, especially in the realm of visuospatial memory. The ability to manipulate and integrate spatial information is crucial for a variety of motor and cognitive activities, ranging from writing to executing complex tasks that require planning and coordination. Recent studies have shown that visuospatial working memory plays a vital role in motor development among children. For instance, children with stronger visuospatial working memory tend to perform better in tasks requiring fine motor skills, such as handwriting and geometric drawing. These

findings highlight that visuospatial working memory not only aids the efficient execution of motor tasks but also serves as a key factor in overall academic development, particularly in tasks that demand motor precision (Eriksen *et al.*, 2023; Serra *et al.*, 2021).

2.2 Working Memory and Inhibitory Control

Inhibitory control, a key executive function, plays a crucial role in cognitive functioning by allowing individuals to suppress automatic impulses and irrelevant responses, thereby promoting goal-directed behaviors (Tiego *et al.*, 2018). This capability is essential for regulating behavior and efficiently executing tasks that require sustained attention and cognitive control (Kang *et al.*, 2022). Working memory, which allows for the temporary storage and manipulation of information, is closely linked with inhibitory control. This relationship is fundamental for maintaining focus on relevant goals while filtering out distractions, particularly in educational contexts where concentration and attention are constantly required (Miyake & Friedman, 2012; Zelazo, 2015).

Recent research underscores the importance of inhibitory control for academic success, demonstrating that it is strongly associated with enhanced performance in areas requiring logical reasoning, problem-solving, and complex decision-making (Zelazo, 2015; Miyake & Friedman, 2012; Ching, 2023; Lee, 2023). Studies have identified a significant positive correlation between working memory and inhibitory control in school-aged children, showing that those with better-developed skills in both domains tend to achieve higher scores in math and reading assessments (Peng *et al.*, 2019; Souissi, Chamari, & Bellaj, 2022; Ching, 2023; Lee, 2023). These findings suggest that working memory serves as a critical mediator in the relationship between inhibitory control and academic achievement, aiding in the effective management of cognitive resources in demanding learning environments (Peng *et al.*, 2019; Sia, Holmboe, & Mani, 2023).

Moreover, inhibitory control is closely linked to the development of self-regulation skills, which are vital for long-term academic success (Johnson *et al.*, 2023). Children who possess stronger inhibitory control are more capable of delaying immediate gratification in favor of pursuing long-term academic objectives, such as preparing for exams or completing intricate assignments (Twito *et al.*, 2019). This level of self-regulation, enhanced by strong working memory, leads to greater academic engagement and perseverance, both of which are essential for sustained academic achievement (Duckworth *et al.*, 2019; Miyake & Friedman, 2012).

2.3 Working Memory and Language Skills

Language skills, particularly phonological awareness, reading, and writing, are deeply influenced by verbal working memory capacity (Viesel-Nordmeyer *et al.*, 2022). Verbal working memory not only supports the processing and retention of linguistic information but also facilitates the learning and application of these skills throughout childhood and adolescence (Jackson *et al.*, 2021). Studies reinforce the idea that this type of memory serves as a fundamental pillar for academic success in literacy and language areas (Jones *et al.*, 2020; Shvartsman & Shaul, 2023). For example, Talli & Stavrakaki (2020)

demonstrated that verbal working memory is a reliable predictor of reading success, showing that children with superior skills in this area are better able to segment and manipulate sounds within words, a critical skill for early literacy. This phonological manipulation ability allows children to develop a stronger understanding of the relationships between sounds and letters, which is crucial for acquiring reading and writing competencies (Milankov *et al.* 2021; Siregar, Khairani, & Lubis, 2023).

Furthermore, the literature indicates that deficiencies in working memory are directly associated with persistent difficulties in reading and writing, including conditions such as dyslexia. The meta-analysis by Melby-Lervåg and Hulme (2013) reviewed longitudinal studies and confirmed that problems with verbal working memory often precede significant difficulties in acquiring written language. These findings suggest that such difficulties can be mitigated by early interventions focused on strengthening working memory. Children who present deficits in this area may, therefore, benefit from pedagogical strategies that promote the improvement of working memory, aiming to prevent or reduce the impact of conditions such as dyslexia. Thus, verbal working memory not only plays a crucial role in language learning but also stands as a key target for educational interventions, with the potential to significantly transform the academic trajectory of vulnerable students.

3. Material and Methods

3.1 Participants

The study included 1107 students, aged between 7 and 10 (±9.45) years old, in the third, fourth and fifth years of Brazilian Elementary School of a public school in Joinville's city, Santa Catarina, Brazil.

The inclusion and exclusion criteria of children's selection were:

- Present indications of proficient school performance proven by legal documents issued by the pedagogical team of the school in which they were enrolled;
- Have an estimated IQ (Wechsler Intelligence Scale for Children—WISC-IV) above 80;
- Do not use psychoactive medication;
- Do not show expressive symptoms of inattention, hyperactivity, or impulsivity through the SNAP-IV evaluation;
- Do not have visual or auditory disorders, heart disease, orthopedic disorders, or behavioral disorders (according to medical evaluation throughout the study).

3.2 Cognitive and Motor Analysis

3.2.1 Working Memory

The study used the Neuropsychopedagogical Screening Scale for Working Memory (NSSWM) to assess working memory, involving 23 items that evaluate complex cognitive processes combining temporary storage and processing of information required for tasks such as language comprehension, reading, arithmetic, and problem-solving (Padilha &

Cardoso, 2022). A 5-point Likert scale measured the frequency of symptom manifestation in children across educational settings. Scores ranged from one point for "not at all like your child" to five points for "very much like your child," with total scores ranging from 23 to 115 points, with a score of 70 points or above being considered within the expected range.

3.2.2 Motor Skills

The teachers of the participating children used the Neuropsychopedagogical Screening for Children's Motor Development to assess the students' motor skills during school activities (Carenzi, Batista & Cardoso, 2024). This screening includes 7 items that address everyday scenarios related to motor coordination, fine motor control, and organizational skills. The teachers evaluated statements about their students' motor characteristics, assigning scores from one to five points based on the frequency and accuracy with which these behaviors were observed in the classroom, with total scores ranging from 7 to 35 points, as this scale identifies occurrences, lower scores indicate better performance. Therefore, to be within the expected range, a score of 20 points or less is required.

3.3.3 Inhibitory Control

Teachers of the participating children used the Child Inhibitory Control Screening Scale (CICS) to assess the student's ability to control inhibitory responses during school activities (Santos & Cardoso, 2023). The SSIC includes 18 everyday scenarios related to inhibitory control, planning, and cognitive and motor impulsivity. Teachers evaluated statements about their students' traits, assigning scores from one to five points based on how well each statement described the child. They then totaled these values to calculate a score ranging from 18 to 90 points, with a score of 61 points or above being considered within the expected range.

3.3.4 Phonological Skills

The study employed the Screening Scale for Phonological Skills (SSPS) to assess phonological skills, focusing on the metalinguistic ability to recognize the formal characteristics of language. The SSPS consists of 7 items for children aged 4-5 years and 17 items for those aged 6-10 years. It evaluates the child's ability to build phonological awareness, identify rhymes, and recognize words that begin and end with the same sounds and phonemes (Cardoso *et al.*, 2024). Teachers rated their students' traits on a scale from one point for "not at all like my child" to five points for "quite like my child." The total score ranged from 1 to 70 points for children aged 6-10, with a score of 56 points or above being considered within the expected range.

3.3.5 Reading and Writing Skills

Teachers used the Children's Reading and Writing Screening Scale (CRWSS) to evaluate students' reading and writing skills (Bassôa *et al.*, 2021). The CRWSS employs a 4-point Likert scale across 16 items to gauge the frequency of potential difficulties in acquiring

reading and writing skills in the school setting. The scoring system ranges from one point for "never" to five points for "always". Total scores vary from 15 points, indicating no difficulty, to 75 points, indicating significant difficulty, as this scale identifies occurrences, lower scores indicate better performance. Therefore, to be within the expected range, a score of 29 points or less is required.

4. Results and Discussion

4.1 Results

By observing Table 01, it is possible to see that, regarding Working Memory skills, the children presented scores ranging from a minimum of 19 points to a maximum of 95 points, with an average of 72.91 points and a standard deviation of 19.94. It was also observed that ±39% of the children were classified as at risk (scores below 70 points), while ±61% were within the expected range.

Regarding motor skills (Motor Development), the scores ranged from 7 to 35 points, with an average of 12.15 and a standard deviation of 7.21. In this area, ±20% of the children were identified as at risk (scores above 20 points), and ±80% were within the expected range.

In terms of Inhibitory Control skills, the scores exhibited a similar range, spanning from 18 to 90 points. The average score was 68.86 points, with a standard deviation of 20.50. On this scale, ±34% of the children were classified as at risk (scores below 61 points), while ±66% were within the expected range.

Table 1: Descriptive Statistics for Cognitive and Motor Skill Variables

Variables	Working Memory	Motor Skills	Inhibitory Control	Phonological Skills	Reading and Writing Skills
Minimum	19,00	7,000	18,00	14,00	15,00
Maximum	95,00	35,00	90,00	70,00	75,00
Mean	72,91	12,15	68,86	55,32	39,65
Std. Deviation	19,94	7,20	20,50	15,70	18,39

Further observation of the aforementioned table reveals that, regarding Phonological Awareness skills, the children's scores ranged from 14 to 70 points, with an average of 55.32 points and a standard deviation of 15.70. Here, ±38% of the children were at risk (scores below 56 points), while ±62% were within the expected range.

As for Reading and Writing skills, the scores ranged from 15 to 75 points, with an average of 39.65 and a standard deviation of 18.39. In this category, ±32% of the children were classified as having performance within the expected range (scores below 30 points), while ±68% were at risk.

Starting with Motor Development, the correlation with Working Memory was found to be the strongest among all, with a correlation coefficient of r=0.916. This indicates an extremely strong linear association. The P-value of P=0.012 reflects the statistical significance of this correlation, reinforcing the robustness of the association

between these two variables. This suggests that as scores in Motor Development increase, there is a very consistent decrease in Working Memory scores.

Given the importance of Working Memory for learning, Pearson's correlation was also used to examine the relationships between Working Memory and three other variables—Inhibitory Control, Phonological Awareness, and Reading and Writing—which also revealed strong and statistically significant linear associations.

Specifically, the correlation between Working Memory and Inhibitory Control resulted in a correlation coefficient of r=0.732, indicating a strong positive linear association. The associated P-value was P=0.028, demonstrating that this correlation is statistically significant at the 5% level, suggesting that increases in Inhibitory Control are positively associated with increases in Working Memory.

Similarly, the correlation between Working Memory and Phonological Awareness showed an even stronger coefficient, with r=0.815. The P-value for this correlation was P=0.034, again showing statistical significance. This result reinforces the idea of a robust positive linear relationship between Phonological Awareness and Working Memory, indicating that as scores in Phonological Awareness increase, scores in Working Memory also significantly increase.

The strongest association among the cognitive skills was observed between Working Memory and Reading and Writing, with a correlation coefficient of r=0.863. The corresponding P-value was P=0.023, confirming that this correlation is significant. These values suggest a very strong association, where higher scores in Reading and Writing are strongly correlated with higher scores in Working Memory.

In summary, all the correlation coefficients (R) are high, and the P-values demonstrate statistical significance, confirming that the variables Inhibitory Control, Phonological Awareness, Reading and Writing, and Motor Development are strongly associated with Working Memory. This indicates that these variables may have a substantial impact on children's performance in skills related to Working Memory.

4.2 Discussion

Regarding Motor Development, the average score of 12.15 points, with a standard deviation of 7.21, and the strong positive correlation with Working Memory (r=0.916, P=0.012) reveal a significant and noteworthy finding. Recent studies, such as those by Cinar *et al.* (2023), Moron, Barbosa & Sanfelice (2023) and van der Fels *et al.* (2019), suggest that motor and cognitive development generally progress in an integrated manner, with beneficial interactions between motor activities and the enhancement of executive functions, including Working Memory. However, the strong positive correlation observed in this study, where higher scores in Motor Development indicate poorer performance, suggests that children with greater motor difficulties also tend to experience challenges with Working Memory.

Bao *et al.* (2024) identified through a comprehensive systematic review that children with motor difficulties frequently face challenges in cognitive and academic tasks, suggesting that these motor difficulties may have a cascading effect on overall

academic performance. Furthermore, studies such as those by Lopes *et al.* (2022) point out that the lack of adequate motor stimulation can exacerbate pre-existing cognitive difficulties, which may be contributing to the positive correlation observed.

Additionally, the strong correlation between Working Memory and Inhibitory Control (r=0.732, P=0.028) is consistent with the literature that emphasizes the interdependence of these executive functions. Recent studies, such as those by Zelazo and Carlson (2022), highlight that Inhibitory Control is crucial for Working Memory, as it allows children to maintain focus on relevant tasks while inhibiting distractions and impulsive responses. This relationship is fundamental for academic success, particularly in subjects that require logical reasoning and problem-solving. The similarity in average Inhibitory Control scores (68.86 points) and the proportion of children at risk (±34%) observed in this study reflect findings from studies such as those by Ahmed *et al.* (2023) and Best, Miller, and Naglieri (2011), which reported difficulties in inhibitory control in approximately one-third of school-aged children. This underscores the need for interventions focused on strengthening inhibitory control to improve Working Memory and, consequently, academic performance.

When examining the relationship between Working Memory and language skills, particularly Phonological Awareness and Reading and Writing, the results are quite revealing. The strong correlation between Working Memory and Phonological Awareness (r=0.815, P=0.034) aligns with the findings of Míguez-Álvarez, Cuevas-Alonso & Saavedra (2022) and Justi, Henriques& dos Reis Justi (2021), which suggest that Working Memory plays a central role in the development of phonological awareness, which is crucial for early literacy. These correlations indicate that improvements in Working Memory could have a significant impact on the development of phonological skills, a conclusion also supported by meta-analysis studies such as that of Melby-Lervåg and Hulme (2013), which identify a bidirectional relationship between these variables.

However, the results related to Reading and Writing skills present an alarming perspective, with an average score of 39.65 points and ±68% of children scoring below the expected level. This figure is significantly higher than reported in other recent studies, such as Cain (2023) and Kim (2022), which identified a prevalence of reading and writing difficulties in about 25% to 35% of school-aged children. The substantial discrepancy observed in this study may suggest that the children evaluated here face additional challenges beyond those identified in the current literature (Perazzo *et al.*, 2022).

Moreover, the significant correlation between Working Memory and Reading and Writing (r=0.863, P=0.023) reflects the strong interdependence of these skills, which has already been highlighted in research such as that by Friso-van den Bos & van de Weijer-Bergsma (2019), which identifies Working Memory as a key predictor of success in reading and writing. This finding is corroborated by studies such as Peng *et al.* (2019), which suggest that Working Memory plays a crucial role in children's ability to decode words, comprehend texts, and produce coherent writing. The robustness of this correlation indicates that interventions focused on improving Working Memory could

have a significant effect on enhancing Reading and Writing skills, particularly in populations that are already at high risk.

Another point to consider is the possibility that the pedagogical practices adopted in the schools attended by the children in this study may not be adequately addressing the needs of students with reading and writing difficulties. Research such as that by Bonte & Brem (2024) suggests that the effectiveness of educational interventions in reading and writing heavily depends on a pedagogical approach that is sensitive to individual differences in Working Memory skills. This reinforces the importance of an adapted curriculum that not only integrates strategies to strengthen Working Memory but also can identify and meeting the specific needs of each student (Darling-Hammond *et al.*, 2019; Jones *et al.*, 2020).

Finally, the high rate of children at risk observed suggests that, in addition to pedagogical interventions, a joint effort among schools, families, and the community may be necessary to mitigate the external factors contributing to these difficulties. Family support programs, increased access to educational resources, and public policies aimed at equity in education may be essential to reversing this troubling scenario (Raghupathi & Raghupathi, 2020).

5. Conclusion

The results of this study reveal a comprehensive view of the interrelationships between Working Memory, Inhibitory Control, Phonological Awareness, Reading and Writing, and Motor Development in elementary school children. The data analysis showed that a significant portion of the children scored below the expected levels, especially in crucial areas such as Reading and Writing and Working Memory, suggesting the need for systematic, effective, and targeted neuropsychopedagogical educational interventions.

The strong positive correlation between Working Memory and other cognitive skills, such as Inhibitory Control and Phonological Awareness, reflects the interdependence of these executive functions and highlights the importance of neuropsychopedagogical interventions that integrate cognitive development holistically, aiming to enhance Executive Functions in students. The difficulties observed in Reading and Writing, with a higher prevalence than recorded in previous studies, suggest that contextual and methodological factors may be playing a significant role in children's academic performance. This points to the need for a review of current pedagogical practices and greater sensitivity to the socioeconomic and environmental variables that affect learning.

Furthermore, the relationship between Motor Development and cognitive skills identified in the study suggests that these areas should not be treated in isolation. Neuropsychopedagogical interventions that simultaneously address motor and cognitive development can be crucial in improving overall student performance.

Therefore, the implications of this study are clear: an integrated educational approach is needed, one that considers both cognitive and motor skills and is adapted to

the individual needs of students. Early and personalized interventions, combined with a learning environment that supports both motor and cognitive development, can not only improve academic performance but also promote the holistic development of children. The adoption of such practices could, therefore, significantly reduce the prevalence of learning difficulties and create a more solid path for children's academic and personal success.

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