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IMPACT OF A NEUROPSYCHOPEDAGOGICAL MOTOR PROGRAM ON EXECUTIVE FUNCTIONS AND LANGUAGE SKILLS IN PRESCHOOLERS

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Abstract

This study aimed to evaluate the effects of a Neuropsychopedagogical Motor Intervention Program (NMIP) on executive functions and language skills in preschool children. The sample included 621 children, aged 4 to 6 years, enrolled in public schools in southern Brazil. Inclusion criteria required proficient school performance, an estimated IQ above 80 (WISC-IV), and the absence of psychoactive medication, significant attention or behavioral disorders, or sensory or physical impairments. Executive functions were assessed through teacher-completed screening scales. The Child Inhibitory Control Screening Scale (CICS) evaluated inhibitory control across

18 everyday scenarios, with scores ranging from 18 to 90 points (expected ≥44). The Neuropsychopedagogical Screening Scale for Working Memory (NSSWM) measured working memory using 23 items rated on a 5-point Likert scale, with scores ranging from 23 to 115 points (expected ≥70). Phonological skills were assessed using the Screening Scale for Phonological Skills (SSPS), comprising 17 items with scores ranging from 1 to 70 (expected ≥56). Reading and writing abilities were evaluated using the Reading and Writing Skills Screening Scale (RSRWS), a 12-item tool with a scoring range of 12 to 60 points (expected ≥42).The NMIP consisted of 36 sessions, 15 minutes each, based on the "Coordenando-se" methodology. Activities included matching geometric shapes and colors to body movements to enhance motor development, executive functions, and mindfulness. Post-intervention results revealed significant improvements in inhibitory control (12.7%), working memory (11.6%), phonological skills (19.1%), and reading and writing skills (37.2%) ($p<0.01$). The percentage of children performing below expected thresholds decreased across all measures.

These findings underscore the potential of structured motor-based interventions to enhance executive functions and language skills in preschoolers, highlighting the NMIP's applicability in early education to foster equitable cognitive and academic development.

Keywords: *executive functions, Neuropsychopedagogy, Language Development, Motor-Based Interventions, children's.*

1. Introduction

During preschool years, brain plasticity creates a crucial window for the development of executive functions, which are significantly shaped by pedagogical experiences and social interactions. Research in developmental neuroscience highlights that early interventions aimed at strengthening these skills are associated with advances in learning, greater socio-emotional competence, and more efficient adaptation to school challenges [1].

This period, marked by rapid cognitive progress, provides ideal conditions for the implementation of pedagogical approaches that integrate the stimulation of executive functions into the school curriculum. These strategies aim to optimize learning and prevent future educational difficulties. Although executive functions are in their early stages of development during preschool, their importance for adapting to the school environment and succeeding in structured activities is widely recognized. They directly influence behaviors

such as sustained attention, impulse control, following instructions, and problem-solving—key skills for formal learning [2,3].

Basic executive functions, including inhibition, working memory, and cognitive flexibility, undergo significant development throughout childhood and adolescence [4]. These skills not only predict academic performance but are also frequently compromised in developmental disorders and learning difficulties [5,6]. For instance, inhibition involves controlling impulses and filtering irrelevant stimuli, which is essential for maintaining focus and regulating classroom behavior [7]. Working memory allows the retention and manipulation of information over short periods, playing a central role in complex tasks such as mental calculations and following instructions [8]. Cognitive flexibility, on the other hand, refers to the ability to switch between different demands or tasks, such as processing visual and verbal information simultaneously [9].

Research indicates that executive functions are positively related to performance in scientific activities, such as problem-solving and hypothesis formulation, although many of these studies focus on preschoolers or employ theoretical questioning tasks rather than hands-on practices [10,11]. While these functions are considered essential for scientific thinking [12], the association between executive functions and scientific problem-solving in school-aged children remains underexplored [13,14].

The transition from preschool to elementary school represents a key moment in the development of executive functions, coinciding with significant advancements in early academic skills such as literacy and mathematics [15]. Studies show that early performance in these areas is a strong predictor of long-term academic success [16,17,18]. For example, Siegler and colleagues demonstrated that early mathematical skills acquired during childhood have a direct impact on future mathematics performance [19].

1.1. Executive Functions and Literacy Development in Preschool

Core components of executive functions, such as inhibition (inhibitory control), updating and mental manipulation of information (working memory), and shifting (cognitive flexibility), play a critical role in reading comprehension, as described in theoretical reviews [20,21].

Inhibitory control is an essential cognitive skill in literacy development as it helps children regulate impulses and focus on relevant information [22]. This ability is subdivided into two main components: response inhibition, which prevents inappropriate impulsive actions, and interference control, which filters out irrelevant stimuli for the task. Studies indicate that

interference control is directly related to phonological awareness, an essential precursor to literacy, allowing children to process sounds and syllables while ignoring distractions [23]. This skill also supports learning sound-letter correspondences, which is crucial for emerging reading and writing [24].

Longitudinal research shows that children with better inhibitory control, particularly in interference control, make more significant progress in literacy skills such as letter identification and phonological awareness [25]. This relationship persists even when controlling for variables such as vocabulary and working memory. Thus, developing inhibitory control at an early age can facilitate learning foundational literacy skills, emphasizing the importance of interventions that foster focus and behavioral regulation during the early school years [26].

Working memory (WM) plays a crucial role in developing language, reading, and writing skills, although there are differences regarding its components' relationship with these abilities. Phonological WM is strongly linked to phonological awareness and reading acquisition, while the phonological loop is essential for processing sounds and letters. Visual-spatial WM has shown contradictory results, sometimes compensating for language deficits [27].

The central executive of WM, though less explored, may influence reading, particularly when interacting with the phonological loop. During reading acquisition, WM aids in sound-letter encoding and is an early indicator of difficulties [28]. Studies suggest that children with low WM capacity are more likely to underperform academically. Identifying how WM relates to early language and math skills is critical to preventing future challenges [29,30,31].

Cognitive flexibility plays a fundamental role in literacy development, particularly in the initial phase of acquiring reading and writing skills. This ability, which involves switching between different conceptual representations, is essential for coordinating multiple linguistic processing elements, such as phonology, morphology, and orthography [32]. Studies show that children with greater cognitive flexibility perform better in emerging literacy skills, including phonological awareness and word recognition. This capacity facilitates transitions between linguistic demands, helping children integrate new information during reading and select strategies for solving language-related problems[33,34,35].

Additionally, cognitive flexibility is associated with children's ability to handle complex structures, such as variations between orthography and phonology [36]. This skill allows beginning readers to process and adapt quickly to specific writing system characteristics, such

as transparent or opaque orthographies [37]. Therefore, interventions promoting cognitive flexibility development can effectively support children at risk for literacy difficulties, providing them with greater adaptability to early academic demands and improving their reading and writing performance [38].

Although the relationship between executive functions and literacy is evident, research suggests that their effects on reading may vary depending on the evaluated component, with working memory most frequently associated with reading comprehension [39]. Writing, in turn, involves foundational skills such as handwriting and spelling and higher-order processes like planning and revising, requiring intense coordination of executive functions [40]. Initially, children heavily rely on these functions to execute writing tasks, such as letter formation and maintaining textual sequence (Hurschler Lichtsteiner, Wicki & Falmann, 2018).

Based on the discussion above, this study aimed to establish the effects of a neuropsychopedagogical motor program (NMIP) on executive functioning and language skills in preschoolers.

2. Method

2.1. Participants

The study included 621 students, aged between 4 and 6 (±4.85) years old, preschoolers from public schools in the Southern Region of Brazil third.

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)..

2.2. Executive Functions and Language Analysis

2.2.1 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 [41]. 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 37 points or above being considered within the expected range.

2.2.2 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 [42]. 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 37 points or above being considered within the expected range.

2.2.3 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 17 items for children aged 4-5 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 [43]. 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 4-6, with a score of 56 points or above being considered within the expected range.

2.2.4 Reading and Writing Skills

Teachers used the Neuropsychopedagogical Screening for Reading and Writing Skills (RSRWS) in Preschoolers is designed to assess the early development of reading and writing abilities in preschool-aged children [44]. This scale consists of 12 items scored on a 1 to 5

scale, where 1 indicates "Not at all similar" to the child's observed behavior or skill, and 5 indicates "Very similar." The expected total score is above 42 points, which represents the minimum threshold for indicating adequate development of the evaluated skills. Scores below this level may suggest the need for neuropsychopedagogical interventions to support and enhance the child's development. This screening tool is an essential resource for education and neuropsychopedagogy professionals, facilitating the early identification of potential challenges and guiding actions to promote effective learning in young children.

2.3. Intervention Procedures

NMIP includes 24 activities grounded in motor development theory, significantly supporting children's cognitive growth. This program focuses on activities that enhance hand and foot coordination, emphasizing the coding and decoding of body movements through cards with geometric shapes and colors. The program aims to bolster motor development, executive functions, and mindfulness. It consists of 36 sessions, each 15 minutes long, conducted in the classroom by the teacher based on the "Coordenando-se" methodology's theoretical principles. Coordenando-se (‘Coordinating’, our translation) activities involve matching figures with specific colors to body parts, requiring the child to observe the colored figure and position the corresponding body part accordingly, performed a previous study with learning difficulties’ children [45,46].

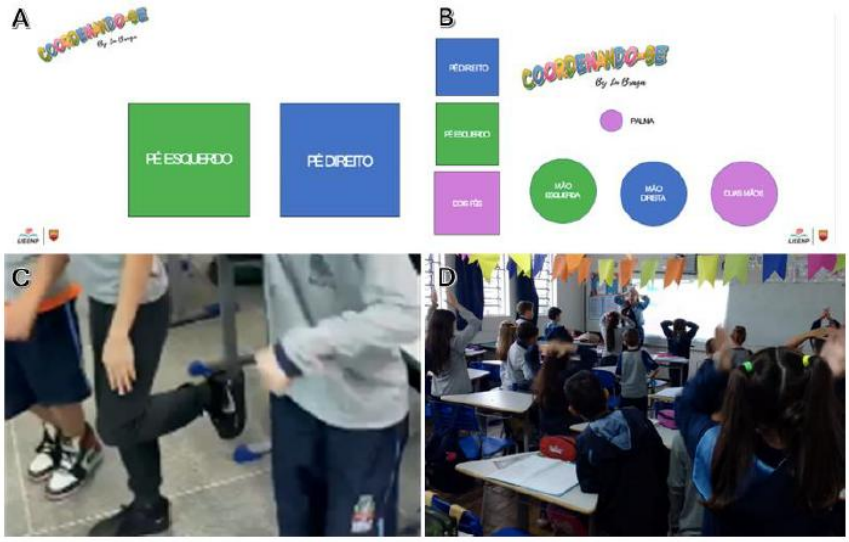

Figure 01: Implement the Neuropsychopedagogical Motor Intervention Program (NMIP) in a classroom setting. (A) displays a directive from the NMIP's initial session, where a child, upon viewing a green square, is to balance solely on their left foot, and upon seeing a blue square, to balance solely on their right foot. (B) advances to the tenth NMIP session, where

the complexity of directives increases: the green square continues to signify balancing on the left foot, the blue square for the right foot, the pink square for tapping both feet, the blue circle for elevating the right arm, the green circle for lifting only the left arm, the pink circle for raising both arms, and the small pink circle indicates clapping. In (C), we observe children executing these initial directives from the first NMIP session. Finally, (D) presents children performing the advanced directives from the NMIP's tenth session.

2.4. Statistical Analysis

Statistical Analysis Initially, the results for the scales were calculated using descriptive statistics, including mean and standard deviation. The obtained data were classified as parametric using the Shapiro-Wilk test. The t-test was used to compare two paired samples.

3. Results

When analyzing the results obtained regarding the children's Inhibitory Control capacity (Figure 02a), it is noticeable that in the 1st Evaluation, the minimum recorded value was 18.00, and in the 2nd Evaluation, it remained the same at 18.00, indicating that the lowest individual performance did not change between the two evaluations. The maximum value also remained constant at 90.00, suggesting that the highest performance achieved in the evaluations was consistent. A significant improvement in the average score was observed, increasing from 66.77 in the 1st Evaluation to 75.27 in the 2nd Evaluation, indicating an approximately 12.7% increase in the average Inhibitory Control performance. This increase suggests an overall improvement in the children's inhibitory control skills over time, as evidenced by a paired t-test result of $p<0.01$. Comparing the results with the expected range for the age group, as determined by the scale used, it was identified that in the first evaluation, approximately 17.5% of the children scored below or equal to 44 points, whereas in the second evaluation, this percentage dropped to only 5.43%.

Figure 2b shows the results of two evaluations of the children's working memory. In the 1st Evaluation, the minimum recorded value was 20.00, while in the 2nd Evaluation, this minimum value slightly decreased to 19.00, indicating a slight variation in the lowest performance. Another important highlight is that the average performance of children in working memory skills showed a significant increase, rising from 63.71 points in the 1st Evaluation to 71.14 points in the 2nd Evaluation, which represents an approximate 11.6% increase in the average performance of these children. Statistical analysis using a paired t-test

shows that the NMIP had a positive impact on the children's working memory skills, as evidenced by a $p<0.01$. Comparing with the expected value for the age group, as determined by the NSSWM, it was identified that in the first evaluation, 19.56% of the children performed below the expected range, whereas in the second evaluation, this percentage dropped to 11.95%.

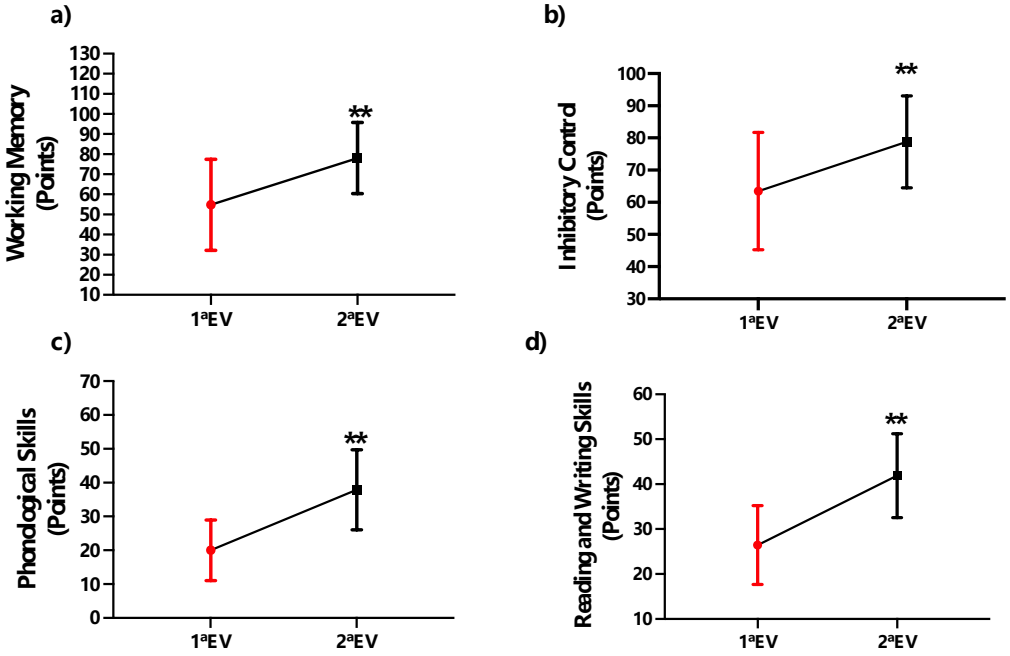

Figure 2: Comparison of executive functions and academic skills across two evaluation moments (1ª EV and 2ª EV). The graphs represent: (a) Working Memory, (b) Inhibitory Control, (c) Phonological Skills, and (d) Reading and Writing Skills. Significant improvements were observed between the first (red) and second (black) evaluations (**$p < 0.01$**), as indicated by the asterisks. Data are expressed as mean ± standard deviation.

When evaluating phonological awareness skills (Figure 2c) during the first assessment, it was observed that the minimum score recorded in the 1st Evaluation was 14.00 points, while in the 2nd Evaluation, this minimum score decreased slightly to 13.00 points, indicating a slight downward variation in the lowest individual performance. On the other hand, the maximum score dropped from 61.00 points in the 1st Evaluation to 56.00 points in the 2nd Evaluation, suggesting a small reduction in the highest performance. However, it is important to highlight that the average score showed a significant increase, rising from 25.47 points in the 1st Evaluation to 30.34 points in the 2nd Evaluation, representing an improvement of approximately 19.1% in the average phonological awareness performance following the NMIP. This increase, confirmed by a paired t-test, was significant with a $p<0.01$, demonstrating that the neuropsychopedagogical intervention developed in

the present study had a positive impact, promoting overall advancements in the children's phonological awareness skills. When compared to the expected range for the age group, as determined by the ERHCF, it was identified that in the first evaluation, 54.34% of the children performed below the expected level, whereas in the second evaluation, this percentage dropped to 27.17%.

Figure 2d presents the results of two assessments of the children's reading and writing skills. In the 1st Evaluation, the minimum recorded score was 12.00 points, which remained unchanged in the 2nd Evaluation, indicating no variation in the lowest individual performance. On the other hand, the maximum score increased from 46.00 points in the 1st Evaluation to 58.00 points in the 2nd Evaluation, showing an expansion in the highest performance among the children.

The average reading and writing skills improved significantly, rising from 28.27 points in the 1st Evaluation to 38.79 points in the 2nd Evaluation, representing an improvement of approximately 37.2%. This increase suggests that, after the intervention, there was significant progress in the reading and writing skills of the preschool children, as evidenced by a paired t-test result of $p<0.01$. When compared to the expected range for the age group, as determined by the RNHLEPE, it was found that in the first evaluation, 98.91% of the children performed below the expected level, whereas in the second evaluation, this percentage decreased to 50% of the children remaining at risk for reading and writing skills.

4. Discussion

The intervention was designed to enhance Basic Executive Functions, including Inhibitory Control and Working Memory, which are essential components of cognitive development. The key research question sought to determine: Can improved levels of Basic Executive Functions—Inhibitory Control and Working Memory—influence the growth of language skills? Specifically, the study investigated whether a neuropsychopedagogical motor program, based on the trilogy of body, movement, and cognition, could improve Inhibitory Control and Working Memory, resulting in a positive impact on children's language skills.

Similar studies found that systematic programs like the NMIP can enhance at least the Inhibitory Control skills involved in executive functions. In particular, this study demonstrated that structured interventions like the NMIP have the potential to improve Inhibitory Control skills, specifically in regulating emotions and maintaining task focus [46,47,48].

The results of this study indicated that a program integrating body and movement during the preschool phase is associated with improvements in Inhibitory Control, consistent with previous research findings. A systematic review and meta-analysis comprehensively synthesized the relationship between movement-based interventions (including activities promoting locomotor skills, object control, and stability) and executive functions (encompassing Inhibitory Control, Working Memory, and Cognitive Flexibility) in children [49,50]. A positive association was observed between body and movement-based programs and the enhancement of Inhibitory Control [51].

Building on previous findings [52, 53,54], our research demonstrates that both Inhibitory Control and Working Memory are significantly related to linguistic performance in preschoolers. By identifying both executive functions as additional factors associated with language development, our results contribute to a more comprehensive understanding of the cognitive mechanisms underlying language acquisition.

Our study, conducted with a sample of 621 children, demonstrated that the neuropsychopedagogical motor training program effectively enhanced specific cognitive skills such as Inhibitory Control and Working Memory. These improvements persisted for up to a year after the intervention. Notably, we observed a direct transfer of these skills to the linguistic domain, suggesting that the training fostered broader cognitive development.

The Neuropsychopedagogical Motor Program (NMIP) thus demonstrates great potential for effective integration into early childhood education routines. Its flexible structure allows educators to adapt activities to the specific needs of each class and child, making it a valuable resource for cognitive development. The group-based approach of the NMIP, aligned with recommendations from the literature [55], promotes collaboration and social learning, optimizing intervention outcomes. The ease of implementation and customization of the NMIP contribute to higher educator adherence and, consequently, better results for children.

The reciprocal relationship between the development of Executive Functions (EF) and the improvement of academic skills is consistent with studies showing that EF, particularly Working Memory (WM), can be developed through training [56,57,58]. In our study, this relationship was observed through a systematic program that used repeated practices in motor and cognitive tasks, promoting the enhancement of Inhibitory Control and Working Memory. These findings reinforce the idea that educational approaches integrating the development of EF through neuropsychopedagogical programs can not only improve these skills but also positively impact academic performance, particularly in areas related to phonological and textual comprehension in reading.

5. Conclusion

The results of this study demonstrate that the Neuropsychopedagogical Motor Program (NMIP) is an effective approach for enhancing Basic Executive Functions, particularly Inhibitory Control and Working Memory, as well as for the development of linguistic skills in preschool children. Statistical analysis revealed a significant positive impact, with consistent increases in average performance for inhibitory control, working memory, phonological awareness, and reading and writing skills following the intervention.

This progress reflects the NMIP's ability to promote positive transfers between cognitive and academic skills, aligning with previous studies that emphasize the relationship between strengthening Executive Functions and academic performance. Furthermore, the significant reduction in the number of children scoring below the expected range for their age group underscores the program's effectiveness as a tool for promoting equity in child development.

The NMIP offers an adaptable format, enabling educators to implement activities that integrate body, movement, and cognition into school routines in a practical and effective manner. The program's flexibility facilitates its customization to meet the specific needs of each group or individual, making it a valuable resource in educational contexts.

We conclude that systematic neuropsychopedagogical interventions like the NMIP, based on motor and cognitive practices, represent a promising solution for developing essential learning skills. These findings highlight the importance of integrating neuropsychopedagogical programs into educational policies, considering their potential to positively impact both cognitive and academic development in preschool children.

Acknowledgements

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