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Neuropsychopedagogical Motor Intervention Program Strengthening Inhibitory Control, Working Memory, and Language Abilities in Post-COVID-19 School Returnees

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Abstract

This study aimed to evaluate the effects of a neuropsychopedagogical motor intervention program (NMIP) on the cognitive functioning and academic achievement of students. 201 students aged 7 to 10 participated, randomly assigned to either the control group (103 students underwent two assessments during the NMIP period) or the experimental group (98 students underwent NMIP interspersed with two assessments). The NMIP utilized the Coordinating Methodology, focusing on motor development, executive functions, and mindfulness. It consisted of 36 sessions, each lasting 15 minutes, involving the coding and decoding of figures and colors with parts of the glass human body, implemented by the class teacher in the school setting. Cognitive functioning and academic achievement were assessed using the Children's Scale for Inhibitory Control Screening (CSICS), Neuropsychopedagogical Scale for Working Memory Screening (NSWMS), Scale for Screening Phonological Abilities (SSPA), and Children's Scale for Reading and Writing Screening (CSRWS) before and after the NMIP. The results showed significant improvements in the experimental group: ±19% ($p<0.01$) in CSICS, ±29% ($p<0.01$) in NSWMS, ±23% ($p<0.01$) in SSPA, and a reduction of ±52% ($p<0.01$) in reading and writing difficulties measured by CSRWS. Additionally, ANOVA analysis indicated superior performance ($p<0.01$) in cognitive functions and academic skills among children in the experimental group post-NMIP compared to those in the control group. In conclusion, the NMIP demonstrated substantial positive effects on both cognitive functioning and academic achievement in elementary school students.

Keywords: COVID-19, Neuropsychopedagogy intervention, students, learning difficulties

1. Introduction

The significance of learning challenges is a pivotal concern in Brazilian educational studies. Recent findings from ongoing research underscore learning difficulties as a prevalent concern within the educational environment, highlighting the need for public policies and societal discussions. Moreover, these findings prompt schools to reassess their strategies to address the potential impacts arising from these challenges (Conrad et al., 2022; Fonte & Osti, 2020). Research also underscores the consequences of failing to identify, evaluate, and intervene early, which can contribute to a cycle of exclusion manifested as school dropout, behavioral issues, underemployment, and limited access to further educational opportunities (Coacci et al., 2023; Sarriera et al., 2021).

The COVID-19 pandemic has emerged as a potentially harmful stressor affecting mental well-being in multiple dimensions. Its impact on children and adolescents has significantly disrupted crucial social interactions for psychosocial and emotional development (Viner et al., 2022; Martins-Filho et al., 2020). The pandemic has influenced all aspects of life for nearly two years, transforming global social dynamics. Even before this crisis, children with learning disabilities faced marginalization and limited opportunities for growth in daily life (Raikes et al., 2023; Gabriel et al., 2022).

Global research investigating the impact of the COVID-19 pandemic on academic performance has compared student achievement on standardized assessments before and after the 2020/2021 school lockdown. These studies have

predominantly revealed a significant rise in challenges among children concerning motor skills, literacy, numeracy, and executive functions (Lynch et al., 2023; Li et al., 2022; Appelhans et al., 2021). The stress induced by social isolation can compromise the immune and hormonal systems, potentially increasing the risk of neuroinflammation, heightening the likelihood of central nervous system damage, and altering cognitive abilities, particularly during childhood. Consistent with this perspective, there are documented cases of heightened attention and memory issues, increased irritability, and fluctuations in executive functions among children and adolescents (Beaugrand et al., 2023; Polizzi et al., 2021; Lavigne-Cerván, 2021).

The repercussions of the pandemic may prove especially harsh for youngsters in their early schooling years, primarily due to the disruption of access to early childhood education programs. Moreover, the transition to formal education during this pivotal developmental phase can amplify the repercussions of significant societal events (Cachón-Zagalaz et al., 2020; Masonbrink & Hurley, 2020; Chen et al., 2020). Recent inquiries are indeed documenting various unfavorable consequences of the pandemic for young children, including a decline in school preparedness (Cachón-Zagalaz et al., 2020). One aspect of performance that the pandemic may have particularly impacted is the proficiency in executive functions (EF) among students in early grades (Lavigne-Cerván et al., 2021). Research suggests that during the pandemic lockdown period, children in this age bracket exhibited lower levels of EF compared to assessments conducted on children of the same age before the pandemic (Davies et al., 2021; Frolli et al., 2021).

Recent research suggests that EFs are critical for a child's academic progress from preschool through schooling (Frolli et al., 2021). Skills associated with EF, including inhibitory control (the ability to suppress distracting information and unwanted responses), working memory (the capacity to monitor and manipulate information mentally), and cognitive flexibility (the ability to think flexibly or adapt), are crucial for student's academic performance in the early grades (Loureiro et al., 2022; Munakata & Michaelson, 2021; Diamond & Ling, 2016). In particular, skills essential for literacy prediction, such as inhibition and cognitive flexibility, intertwine. Word reading proficiency correlates with working memory, inhibition, shifting, updating, and attention control. Moreover, reading comprehension, at a minimum, links to planning, working memory, and inhibition (Scionti et al., 2023; Spiegel et al., 2021). These findings highlight the significant impact of EFs on developing academic competencies among school-aged children (Bustamante et al., 2023; Emslander & Scherer, 2022; Diamond, 2013).

The issue of learning challenges and the potential contributions of dialogues between mind (psychology), brain (neuroscience), and educational (pedagogy) sciences (MBES) have long been deliberated, particularly concerning the establishment of an education grounded in a new paradigm that prioritizes the holistic development of students (Alves et al., 2023; Loureiro & Cardoso, 2022; Santos & Sholl-Franco, 2022; Munck et al., 2021; Tokuhama-Espinosa & Nouri, 2020; Tokuhama-Espinosa, 2018). From this standpoint, the Brazilian Society of Neuropsychopedagogy (http://sbnpp.org.br) defines Neuropsychopedagogy as a transdisciplinary field rooted in the principles of neuroscience applied to education, learning theories, and cognitive psychology, expanding the MBES as a professional field of study and application (educational and clinical) (Loureiro et al., 2023; Avelino, 2019). It focuses on exploring the relationship between the nervous system and learning across various contexts, considering individuals (Loureiro & Cardoso, 2022). Given those above, the study aimed to evaluate the effect of a neuropsychopedagogical motor intervention program on the cognitive functioning and academic achievement of students.

2. Method

2.1 Participants

The study involved 201 students aged 7 to 10 (±9.45) years in the third, fourth, and fifth years of a Brazilian public elementary school in Joinville, Santa Catarina, Brazil. The criteria for selecting children included:

- They demonstrated proficient school performance with legal documentation from the school's pedagogical team.
- An estimated IQ (Wechsler Intelligence Scale for Children—WISC-IV) is above 80.
- Do not use psychoactive medication.
- According to the SNAP-IV evaluation, they do not show significant inattention, hyperactivity, or impulsivity symptoms.
- Medical evaluation throughout the study confirmed that they do not have visual or auditory disorders, heart disease, orthopaedic disorders, or behavioural disorders.

2.2 Experimental Design

The study adopted an experimental design (Figure 1), conducting a pre-intervention assessment (1st assessment), implementing a neuropsychopedagogical motor intervention program (NMIP) consisting of 36 sessions of 15 minutes

each, and carrying out a post-intervention assessment (2nd assessment). The children were involved in the research for approximately six months, from the study's introduction to the second assessment. We randomly divided participants into control and experimental groups after the 1st assessment using the Konkuri© software, ensuring an even distribution of gender and age between the groups. The group composition was as follows:

- Control: 103 students (54 girls and 49 boys) only took the two assessments during the NMIP period.
- Experimental: 98 students (54 girls and 44 boys) underwent 36 sessions of the NMIP.

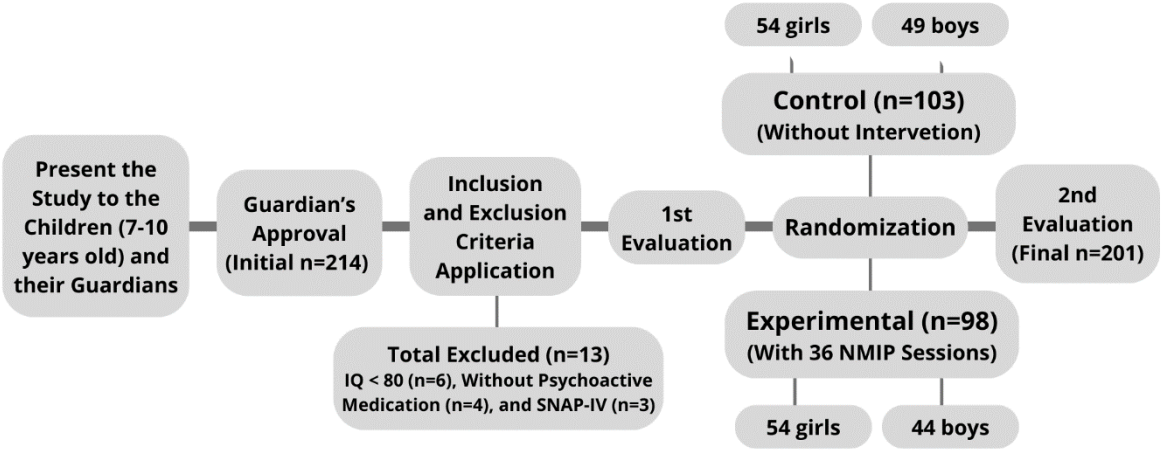

Figure 1. Study flowchart with the division of the study groups

2.3 Cognitive and EFs Analysis

2.3.1 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 (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.

2.3.2 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 (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.

2.3.3 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 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.

2.3.4 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.

2.4 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. Cardoso et al. (2021) performed a previous study with learning difficulties' children

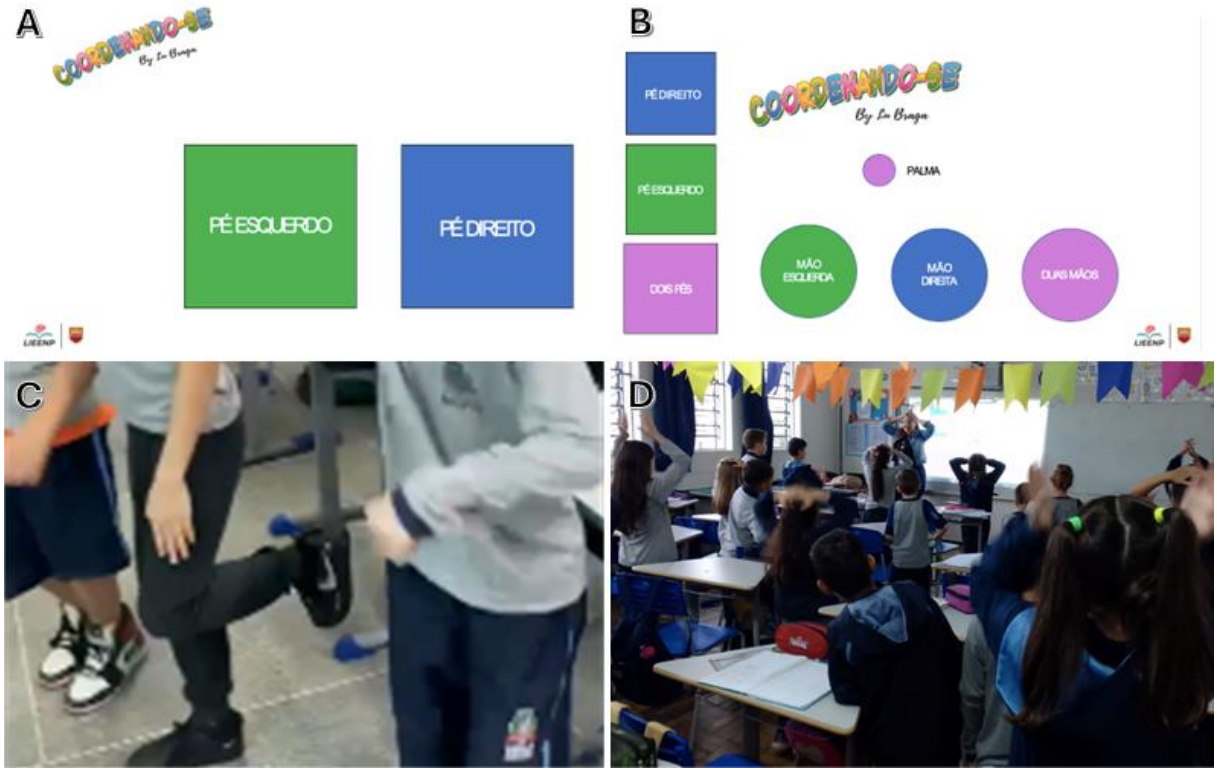

Figure 2. Implement the Neuropsychopedagogical Motor Intervention Program (NMIP) in a classroom setting. (A) displays a directive from the NMIP's initial session, where a child, upon viewing a green square, is to balance solely on their left foot, and upon seeing a blue square, to balance solely on their 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.

2.5 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, and ANOVA was employed to compare the groups.

3. Results

3.1 Inhibitory Control

In the initial assessment, children in the control group scored 64.24±15,54 points. Children in the experimental group scored between 23 and 89 points (63.95±15,35). In the second evaluation, the control group showed no significant increase in inhibitory control aspects, resulting in an average score of 66.13±14,77, ranging from 25 to 90 points. In contrast, children in the experimental group experienced a significant increase of ±19% ($p<0.01$), achieving an average score of 76.23±12,91, with scores ranging from 42 to 90 points (figure 3). When comparing the groups using ANOVA, the scores achieved by children in the experimental group were approximately ±15% higher than those of the control group during the second assessment, a statistically significant difference confirmed by an F-value of 15.18 and a significance level of $p<0.01$.

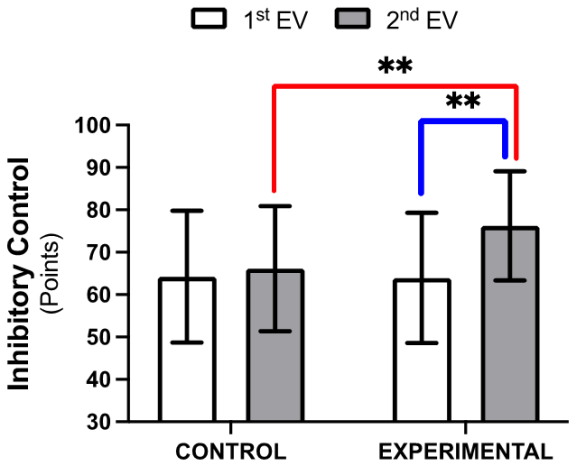

Figure 3. Score in each Child Inhibitory Control Screening Scale (CICS) aspect before (1st EV) and after (2nd EV) NMIP. Effect sizes for the control and experimental groups. Results are expressed as mean and standard deviation. EV, Evaluation; **p<0,01.

3.2 Work Memory

Figure 4 illustrates each Neuropsychopedagogical Screening Scale for Working Memory (NSSWM) aspect's scores before (1st EV) and after (2nd EV) the NMIP. The first evaluation of the control group scored 63±19.74 points, and the experimental group scored 62.24±19.89 points. On reevaluation, the control group's range of scores was 63.16±19.85 points in working memory-related skills. The experimental group improved their scores to 80.37±15.30 points, reflecting a significant increase of approximately 29% (p<0.01) in the NSSWM score. Comparing the groups with ANOVA revealed that the experimental group's scores were about 27% higher than the control group's during the second assessment, a statistically significant improvement confirmed by an F-value of 96.28, with a significance level of p<0.01.

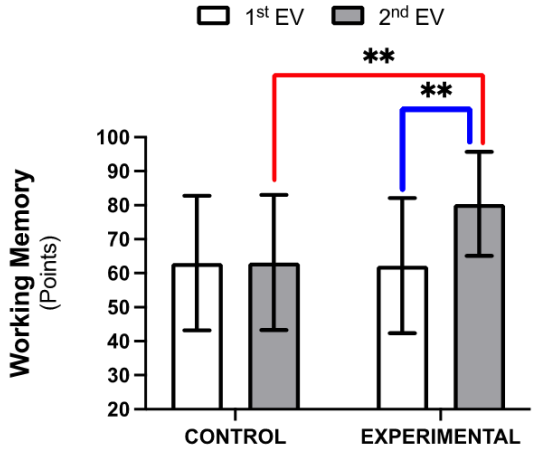

Figure 4. Score in each Neuropsychopedagogical Screening Scale for Working Memory (NSSWM) aspect before (1st EV) and after (2nd EV) NMIP. Effect sizes for the control and experimental groups. Results are expressed as mean and standard deviation. EV, Evaluation; **p<0,01.

3.3 Phonological Skills

In the initial assessment phase, children in the control group displayed an average performance of 52.72±16.11 points. Similarly, their counterparts in the experimental group exhibited a comparable range, scoring 52.36±16.61 points. Following subsequent evaluation, children in the control group demonstrated no significant increase. Conversely, children who underwent the MNIP intervention in the experimental group displayed a shift in performance, with scores of 64.79±8.74 points. Comparing the average scores of the experimental group between the two evaluation points revealed a significant increase of approximately 23% (p<0.01) during the second assessment (Figure 5). Moreover, an apparent disparity of 9.9 points emerged between the two groups during the second evaluation, indicating that the experimental group achieved an average score approximately 18% higher than their counterparts in the control group. To ascertain that this discrepancy was not a chance occurrence but a consequence of the MNIP intervention, an analysis of variance (ANOVA) was conducted, yielding a p-value of less than 0.01, with an F-value of 12.58. This statistical analysis underscores the

significant impact of the MNIP intervention on the performance outcomes of the experimental group.

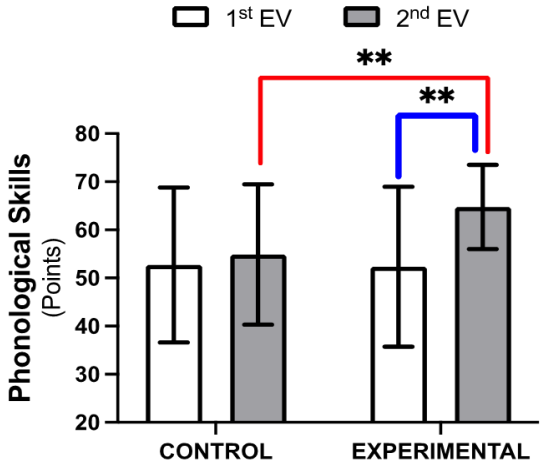

Figure 5. Score in each Screening Scale for Phonological Skills (SSPS) aspect before (1st EV) and after (2nd EV) NMIP. Effect sizes for the control and experimental groups. Results are expressed as mean and standard deviation. EV, Evaluation; **p<0,01.

3.4 Reading and Writing Skills

In the preliminary assessment phase, a comprehensive examination of the reading and writing proficiencies among children within the control group unveiled a spectrum of 43.35±15.52 points. In parallel, counterparts in the experimental group demonstrated a comparable performance of 44.73±15.64 points. Upon subsequent evaluation, children within the control group showcased a range of 41.75±15.11 points. This observation suggests a nominal decrease of approximately 4% ($p>0.05$) in the frequency of encountered challenges related to reading and writing skills among these children, thereby underscoring the inverse relationship between scores and proficiency levels.

Conversely, children in the experimental group displayed a reduction of approximately 54% ($p<0.01$) in the frequency of reading and writing challenges after participating in the MNIP intervention. This reduction was reflected in an average performance of 29.01±15.03 points (Figure 6). Furthermore, upon comparative analysis of both groups during the subsequent evaluation, a gap of 12.74 points emerged, signifying a 43% lower occurrence rate of difficulties among the experimental group compared to their counterparts in the control group. ANOVA was deployed to establish the non-random nature of this discrepancy and attribute it to the effects of the MNIP intervention. It revealed a significant p-value of less than 0.01, supported by an F-value of 17.16. This statistical analysis underscores the substantial impact of the MNIP intervention in mitigating challenges associated with reading and writing skills among children in the experimental group.

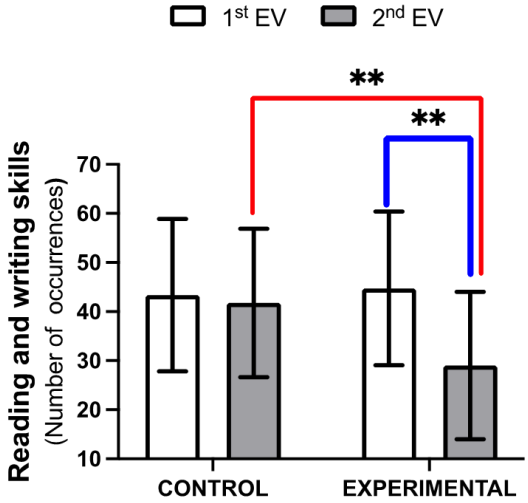

Figure 6. Score in each Children's Reading and Writing Screening Scale (CRWSS) aspect before (1st EV) and after (2nd EV) NMIP. Effect sizes for the control and experimental groups. Results are expressed as mean and standard deviation. EV, Evaluation; **p<0,01.

4. Discussion

The findings from this study underscore the potential of MNIP in significantly enhancing executive functions (EFs) and language-related abilities in typically developing children aged 7 to 10 years. Our results demonstrate improvements across all measured domains, including inhibitory control, working memory, phonological skills, and reading and writing proficiency, within the experimental group compared to the control group. These findings align with prior research studies, corroborating the positive impact of similar interventions on cognitive development (Romero-López et al., 2021; Espinet, Anderson & Zelazo, 2013).

While both groups exhibited increases in scores related to executive functions and language skills, the experimental group demonstrated more substantial improvements. This discrepancy may be attributed to the qualitative differences in pedagogical instruction and intervention methods employed between the two groups (Irmawati et al., 2021; Bodrova & Leong, 2019). Specifically, the "Coordinating Yourself" approach utilized in the neuropsychopedagogical motor intervention likely facilitated the transfer of executive function training to various academic tasks, enhancing cognitive processing (Cardoso et al., 2021b, 2021c).

The integration of body, movement, and cognition within the MNIP underscores the interconnectedness of these domains in promoting cognitive growth. Studies have highlighted the engagement of neural regions associated with cognitive functions during motor tasks, emphasizing the potential of motor-based interventions in enhancing cognitive abilities (Spanou et al., 2022; Cardoso et al., 2021b; Gashaj et al., 2021). The systematic incorporation of motor development tasks within educational settings can serve as a potent catalyst for cognitive enhancement, particularly when coupled with innovative approaches such as the one utilized in our study (Soltani-Kouhbanani & Rothenberger, 2021; Rafiei et al., 2021; Zelazo et al., 2018).

The Executive-Related Learning Efficiency (ERLE) measure emerged as particularly impactful among the assessments conducted in this study, revealing a notable transfer effect from executive functions (EFs) training to academic skills. This underscores the potential of brief, school-based neuropsychopedagogical interventions to enhance EFs and academic proficiencies, including phonological skills, reading, and writing, in elementary school students. The implementation of the "Coordinating Yourself" methodology within our Neuropsychopedagogical Intervention likely facilitated the integration of visual-motor aspects with executive functions, which is essential for proficient reading (Cardoso et al., 2021a, 2021b; Bodrova & Leong, 2024, 2019; Oberer, Gashaj, Roebers, 2018).

Our program's intensive nature likely enabled the utilization of cognitive skills to enhance executive functions and academic abilities related to reading and writing. Therefore, neuropsychopedagogical interventions have the potential to benefit various complex cognitive tasks associated with real-life learning situations, where students must master and apply these skills (Fernandes et al., 2022; Cardoso et al., 2021a, 2021b; Gai et al, 2021; Cartwright et al., 2020; Emami-Kashfi et al, 2019; Lipsey et al., 2017; Alesi et al., 2016). The findings suggest that the MNIP implemented in this study likely contributed to enhancing skills associated with EFs (inhibitory control and working memory) and language abilities (phonological skills and reading and writing) among students in the experimental group. This is evident when comparing the experimental group's performance across all four assessed variables.

These study outcomes are consistent with existing evidence supporting the efficacy of targeting activities involving body, movement, and cognition to enhance executive functions and language skills, thereby promoting school readiness. However, further randomized and controlled studies employing standardized assessment methods and protocols are necessary to provide more precise evidence regarding the potential benefits of neuropsychopedagogical intervention in fostering cognitive development and academic performance in school-aged children.

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Authors contributions

All authors were responsible for the experimental design of the study and its application. The author Lucinara Braga is a leader of the Coordenando-se (‘Coordinating’, our translation). All authors read and approved the final manuscript.

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Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Informed consent

Obtained.

Ethics approval

The Publication Ethics Committee of the Redfame Publishing.

The journal's policies adhere to the Core Practices established by the Committee on Publication Ethics (COPE).

Provenance and peer review

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Data sharing statement

No additional data are available.

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