European Journal of Special Education Research
ISSN: 2501 - 2428
ISSN-L: 2501 - 2428
Available on-line at: www.oapub.org/edu

DOI: 10.46827/ejse.v11i2.5889 Volume 11 │ Issue 2 │ 2025

NEUROPSYCHOPEDAGOGICAL INTERVENTION WITH THE RUBIK'S CUBE: IMPACT ON EXECUTIVE FUNCTIONS AND CORTICAL ACTIVITY IN EARLY ELEMENTARY SCHOOL CHILDREN

Fabrício Bruno Cardoso[1,2i],
Alfred Sholl-Franco[1,2],
Érica Garcia Silveira Gonçalves[3],
Filipi Prado Grimm[3],
Everton Odisi[3],
Aliny Carvalho Dematté[1,2],
João Vitor Galo Esteves[1,2],
Washington Adolfo Batista[1],
Filipe M. Bonone[1]
[1]Educational Innovations and Neuropsychopedagogical Studies
Laboratory of the Faculdade CENSUPEG,
Joinville, Santa Catarina,
Brazil
[2]Núcleo de Divulgação Científica e Ensino de Neurociências (NuDCEN),
Instituto de Biofísica Carlos Chagas Filho (IBCCF),
Programa de Neurobiologia, Universidade Federal do Rio de Janeiro,
Brazil
[3]Projeto Magicubo Neuroeducação,
Secretaria Municipal de Educação de Brusque-SC,
Brazil

Abstract:
Difficulties in academic learning are often associated with deficits in executive functions (EFs), particularly in working memory, inhibitory control, and cognitive flexibility. Among the cognitive processes linked to EFs, rapid automatized naming (RAN) is a key indicator of lexical access efficiency and processing speed, both of which are crucial for reading fluency and academic success. Given its importance, investigating interventions that enhance RAN performance can provide valuable insights into cognitive training strategies. This study examined the effects of a Neuropsychopedagogical Intervention (NPpI) on automatized naming ability in children aged 7 to 9 years. A total of 20 participants were randomly assigned to either an experimental group (EG, n = 10), which received the intervention, or a control group (CG, n = 10), which did not undergo any additional training. The intervention aimed to stimulate cognitive mechanisms

[i] Correspondence: email fabricio@censupeg.com.br

underlying lexical retrieval and processing efficiency through structured cognitive activities. All assessments were conducted after the intervention period, ensuring that performance differences reflected the effects of NPpI. To evaluate outcomes, behavioral performance was measured using the Rapid Automatized Naming (RAN) test, assessing lexical retrieval speed and accuracy. Additionally, electrophysiological measures were obtained through electroencephalography (EEG), specifically analyzing the Theta/Alpha Ratio (TAR) in the parietal region to assess neural efficiency during cognitive processing. The results showed that children in the EG exhibited faster naming times (M = 35.18s, SD = 6.82) compared to the CG (M = 40.19s, SD = 6.03; $p = 0.0232$). Moreover, the EG made fewer errors (M = 1.30, SD = 0.95) than the CG (M = 2.40, SD = 1.07; $p = 0.0415$), indicating improved lexical retrieval accuracy. Electrophysiological findings revealed a significantly lower Theta/Alpha Ratio in the EG, particularly in the PZ electrode (EG: M = 1.88, SD = 0.68 vs. CG: M = 2.73, SD = 0.77; $p < 0.01$), suggesting enhanced neural efficiency following NPpI. These findings support the effectiveness of structured neuropsychopedagogical interventions in enhancing automatized naming performance and modulating cortical activity. The observed improvements in processing speed, accuracy, and neural efficiency reinforce the relevance of integrating cognitive training programs into educational settings. Future research should explore long-term effects, applicability to diverse populations, and broader cognitive outcomes to optimize intervention strategies for learning enhancement.

Keywords: children, executive functions, neuropsychopedagogical intervention, Rubik's cube, theta/alpha ratio, neural efficiency

1. Introduction

Difficulties in academic learning are often linked to deficits in executive functions (EFs), which encompass working memory, inhibitory control, and cognitive flexibility (Diamond, 2013; Khan & Lal, 2023). These cognitive abilities play a crucial role in organizing thoughts, managing tasks, and adapting to new learning situations (Thornhill-Miller *et al.*, 2023). Children with below-average EF performance may struggle with self-regulation, attention control, and efficient information processing, which are essential for reading comprehension, mathematical reasoning, and problem-solving (Ruffini *et al.*, 2024). Moreover, deficits in executive functioning are associated with increased frustration, difficulty following instructions, and lower engagement in classroom activities, further hindering academic achievement(Etokabeka, 2024). As a result, children with EF impairments often require additional instructional support and structured learning strategies to compensate for cognitive inefficiencies (Capodieci *et al.*, 2023). These difficulties can compromise not only academic success but also long-term cognitive development, affecting a child's ability to develop critical thinking, organizational skills, and adaptive learning behaviors (Dwyer, 2023). Given these challenges, targeted interventions aimed at strengthening executive processes are essential to support optimal learning and cognitive growth in school-age children (Lambert, DiCarlo & Rueter, 2025).

Among the various cognitive processes related to learning, automatized naming ability is particularly relevant, as it reflects the speed and accuracy of lexical access, a critical component of reading fluency and verbal processing (Schoenel *et al.*, 2020). Children with impairments in automatized naming may experience delays in language processing, slower reading development, and difficulties in retrieving learned information (Graziani *et al.*, 2024). Since automatized naming is closely linked to broader executive and cognitive functions, improving its efficiency through structured cognitive interventions may positively impact academic performance and learning outcomes (Diamond& Ling, 2016; Marshall *et al.*, 2025).

Neuropsychopedagogical Interventions (NPpI) provide an evidence-based approach to cognitive training in educational settings, integrating neuroscience, psychology, and pedagogy to strengthen cognitive flexibility, attentional control, and processing speed (Loureiro, Souza, & Cardoso, 2022). By engaging children in structured cognitive tasks, NPpI can promote neural efficiency and information retrieval mechanisms, offering potential benefits for automatized naming and other executive functions (Cardoso *et al.*, 2025).

This study aims to examine the effects of a Neuropsychopedagogical Intervention (NPpI) on automatized naming ability in children aged 7 to 9 years. Specifically, it investigates whether engagement in structured cognitive activities improves lexical retrieval speed and accuracy while also assessing neural efficiency through cortical electrical pattern analysis. By integrating behavioral and neurophysiological measures, this research seeks to contribute to the understanding of cognitive processing mechanisms and inform the development of effective intervention strategies for enhancing learning performance in educational contexts.

2. Literature Review

2.1 Executive Functions in Children's Cognitive Development

Executive functions (EFs) are a set of higher-order cognitive skills that enable self-regulation, problem-solving, and adaptation to novel or complex situations. These functions are fundamental to learning, as they allow individuals to plan, organize information, control impulses, and adjust their actions according to specific goals (Ibbotson, 2023). EFs encompass both basic and complex abilities, with working memory, inhibitory control, and cognitive flexibility serving as the foundational executive functions upon which more complex processes, such as planning and decision-making, are built (Sambol *et al.*, 2023). Inhibitory control is strongly associated with prefrontal cortex activity, particularly in the ventrolateral and dorsolateral regions, in interaction with subcortical circuits such as the caudate nucleus and the basal ganglia, which play a role in filtering irrelevant information and modulating motor responses (Friedman & Robbins, 2022). Beyond its relationship with attention and behavior, inhibitory control is also essential for linguistic and motor processes. In the language domain, it enables individuals to filter phonological and semantic interference during verbal production and comprehension, contributing to fluency and discourse coherence (Hertrich *et al.*, 2021). In motor control, this function is crucial for strategy adaptation and coordinated movement execution, including the regulation of eye movements, which are essential for visual orientation and motor precision (Giovannetti & Rancz, 2024). Oculomotor tracking allows individuals to continuously adjust their visual attention, filtering out irrelevant stimuli and focusing on key elements for task execution. This mechanism is closely linked to visuomotor integration, which involves coordination between visual perception and bodily movement, enabling precise adjustments and anticipatory actions (Souto & Kerzel, 2021). Thus, inhibitory control not only regulates impulsive response suppression but also contributes to the fluidity and accuracy of oculomotor and motor movements, which are essential for planning, continuous monitoring, and rapid strategy adjustments, frequently required in educational environments (Apšvalka *et al.*, 2022). Consequently, deficits in inhibitory control are often associated with attention problems, learning difficulties, and impulsivity, negatively impacting school performance and behavioral regulation (Kostyrka-Allchorne *et al.*, 2023). The stimulation of this function through structured interventions can lead to significant improvements in concentration, thought organization, and action planning, all of which are crucial for cognitive and academic development (Robledo-Castro, Hederich-Martínez & Castillo-Ossa, 2023).

Working memory (WM) refers to the ability to temporarily store and manipulate information while performing a cognitive task. It plays a fundamental role in various domains, including problem-solving, reading comprehension, mathematical reasoning, and language development (Zhang, Tolmie, & Gordon, 2022). WM allows individuals to retain relevant information and use it to complete more complex cognitive tasks, making it one of the key components of executive functioning in educational settings (Kazali, 2025). From a neurophysiological and anatomical perspective, the prefrontal cortex is the primary structure involved in WM, working in conjunction with the parietal cortex and subcortical structures such as the hippocampus, which support the maintenance and manipulation of temporary information (Sridhar, Khamaj & Asthana, 2023). Electroencephalography (EEG) studies suggest that efficient WM performance is associated with specific patterns of electrical activity, particularly in the theta (4–7 Hz) and alpha (8–12 Hz) frequency bands (Magosso & Borra, 2024; Perez *et al.*, 2024). Theta activity has been linked to the active maintenance of information, while alpha suppression is associated with increased attentional control during tasks that require cognitive effort (Clements *et al.*, 2022).

Beyond its importance for information storage and manipulation, working memory plays a crucial role in specific cognitive systems, such as the phonological loop, verbal processing mechanisms, and visuomotor processing (Okur& Aksoy, 2025). The phonological loop, for example, enables the temporary retention and manipulation of verbal information, which is essential for language development and reading acquisition (Paas & van Merriënboer, 2020). Meanwhile, visuomotor integration, supported by the interaction between the parietal cortex and prefrontal regions, allows for coordination between visual perception and motor actions, a critical aspect for tasks that require refined motor control and strategic planning (Wang *et al.*, 2024; Florio, 2025).

These findings emphasize the importance of working memory for a wide range of cognitive and motor functions, highlighting its central role in tasks that require retention, manipulation, and integration of information, particularly within educational contexts (Draheim *et al.*, 2022; Morra, Howard & Loaiza, 2025).

Cognitive flexibility is the ability to switch between different tasks or mental strategies, adjusting to environmental demands and allowing for efficient adaptation to new conditions (Shende & Mudar, 2023). This function is directly related to cognitive reconfiguration, enabling individuals to modify thought patterns, adjust previously planned responses, and adopt new approaches when faced with unexpected challenges (Ritz, Leng, & Shenhav, 2022). In addition to its role in creative problem-solving, cognitive flexibility is also associated with oculomotor control and adjustment, facilitating efficient shifts in visual focus between different stimuli (Korda *et al.*, 2024). Adaptive oculomotor tracking allows for the rapid identification of relevant information while filtering out distractions, optimizing visual navigation in dynamic contexts (Hooge *et al.*, 2025). Therefore, cognitive flexibility not only regulates the switching between cognitive strategies but also influences visuomotor adaptation, ensuring an efficient response to demands that require attentional reorientation and coordination between visual perception and action (Zühlsdorff *et al.*, 2023; Cole, 2024).

2.2 Executive Functions and Cortical Electrical Patterns

Electroencephalography (EEG) studies have demonstrated that the efficient functioning of executive functions (EFs) is associated with specific patterns of cortical electrical activity, reflecting the dynamics of cognitive processes involved in working memory, inhibitory control, and cognitive flexibility (Viviani& Vallesi, 2021). Activity in the theta (4–7 Hz) and alpha (8–12 Hz) frequency bands has been extensively studied in relation to working memory, with the former associated with active information maintenance and cognitive control regulation by the prefrontal cortex, while the suppression of the latter is related to the efficient allocation of attentional resources and the inhibition of irrelevant stimuli, optimizing the processing of temporarily stored information (Domic-Siede *et al.*, 2021; Magosso & Borra, 2024; Huang *et al.*, 2024).

Beyond working memory, other executive functions also exhibit characteristic electrophysiological patterns. Inhibitory control has been associated with an increase in beta activity (13–30 Hz) in the frontal region, reflecting an enhancement in the filtering of irrelevant information and the inhibition of automatic responses (Boutzoukas *et al.*, 2021; Wang, & Lyu, 2024). This mechanism is evidenced by event-related potentials (ERPs), such as N2, which reflects conflict monitoring, and P3, associated with attentional regulation and the suppression of inappropriate impulses (Yu, Abdullah & Manso, 2024; Mendes *et al.*, 2024). Meanwhile, cognitive flexibility involves oscillations in the theta frequency range in the medial frontal region, linked to the reconfiguration of cognitive strategies and adaptation to new environmental demands (Cao *et al.*, 2023; Tan *et al.*, 2024; Charlebois-Poirier *et al.*, 2025).

These electrophysiological patterns provide a neurobiological model for understanding how the brain processes information and adjusts its activity to optimize cognitive performance (Vidaurre, 2024). The relationship between executive functions and cortical activity underscores the importance of interventions that can modulate these neural circuits (Bombonato *et al.*, 2024; Tian *et al.*, 2025). Studies indicate that training programs targeting working memory, inhibitory control, and cognitive flexibility can induce neuroplastic changes, leading to greater cognitive efficiency and enhanced neural functionality (Nguyen, Murphy & Andrews, 2019; Whybird *et al.*, 2021; Lesser, Webber& Miglioretti, 2024). Specifically, interventions that stimulate theta activity in the prefrontal and parietal cortex have been associated with improvements in working memory performance, while training focused on inhibitory control regulation has demonstrated increases in beta activity in the frontal region, indicating greater self-regulation capacity and cognitive adaptability (Li *et al.*, 2023; Wu, Wu & Liu, 2024; Tan *et al.*, 2024).

Thus, understanding cortical electrical activity patterns related to executive functions not only enhances knowledge about the neural mechanisms underlying cognitive processing but also supports the development of evidence-based educational strategies (Eng *et al.*, 2022). Interventions that consider cortical activity modulation may represent effective approaches for optimizing cognitive performance in school settings, promoting more efficient development of executive and academic skills in students (Pedroso *et al.*, 2021; Lo *et al.*, 2024).

2.3 Neuropsychopedagogical Intervention and Executive Functions

Recognizing the relevance of executive functions (EFs) for cognitive and academic development, various strategies have been proposed to enhance these skills in educational settings (Perpiñà Martí *et al.*, 2023). Among these strategies, executive function training programs and neuropsychopedagogical interventions (NPpI) stand out, aiming to strengthen abilities such as working memory, inhibitory control, and cognitive flexibility, thereby promoting greater self-regulation and efficiency in information processing (Simão, Corrêa & Ferrandini, 2020; Dos Anjos *et al.*, 2024).

The Neuropsychopedagogical Intervention (NPpI) represents a structured and systematic approach to executive function training within the school environment. By integrating principles from neuroscience, psychology, and pedagogy, this approach ensures that the development of executive functions (EFs) occurs in a contextualized manner, respecting both the academic and individual needs of students (Loureiro, Novaes & Cardoso, 2024).

Research on NPpI has shown that its effects extend beyond the enhancement of basic executive functions, leading to significant transfers to more complex skills, such as academic performance (Cardoso *et al.*, 2021; Loureiro & Cardoso, 2022; Grehs *et al.*, 2024). Studies indicate that students participating in systematized NPpI programs show improvements in reading comprehension, mathematical problem-solving, and cognitive organization, suggesting that this approach can positively impact learning and cognitive development in school settings (Loureiro, Souza, & Cardoso, 2022).

These interventions are applied directly within the school environment, allowing students to train cognitive skills in real learning contexts, where they face concrete challenges that require the practical application of executive functions (Cardoso *et al.*, 2024). This real-world engagement facilitates the generalization of gains to various daily academic tasks, making the benefits of intervention more sustainable and functional (Cardoso *et al.* 2023). Additionally, NPpI is grounded in an integrated approach based on the triad of body, movement, and cognition, recognizing that executive function development occurs through the dynamic interaction between mental activity, sensorimotor experiences, and physical engagement (Cardoso *et al.*, 2025). This perspective highlights the importance of methodologies that integrate cognitive and motor stimuli within the educational context, fostering not only academic learning but also emotional regulation and the development of socio-adaptive skills in students (Diamond *et al.*, 2019; Pradeep *et al.*, 2024).

In this context, strategies that incorporate playful elements have emerged as effective approaches for the development of executive functions in school settings (Souza *et al.*, 2024). The Rubik's Cube, for instance, has gained prominence as a promising tool within NPpI interventions, as it integrates cognition, movement, and problem-solving in an engaging way. Its manipulation requires planning, working memory, inhibitory control, and cognitive flexibility while simultaneously maintaining student engagement through challenge and playfulness. Thus, using the Rubik's Cube as a cognitive stimulation strategy aligns with NPpI principles by offering an interactive and meaningful learning experience, fostering the enhancement of executive functions in real educational contexts (Campelo *et al.*, 2024).

3. Material and Methods

3.1 Research Ethics

This study was approved by the Human Research Ethics Committee (2,625,379), under substantiated opinion no. 517,483; Prior to the start of the study, a Technical-Scientific Cooperation Agreement was signed between the Brusque Municipal Department of Education (SMED) and the CENSUPEG College, for the mutual development of research activities.

3.2 Study Universe

The universe of this study initially consisted of 20 children of both sexes aged between 7 and 9 years old, students from the municipal education network in the city of Brusque/SC.

The inclusion and exclusion criteria for selecting the respective children were:

- Present indications of proficient or non-proficient academic 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 medications.
- Do not present significant symptoms of inattention, hyperactivity or impulsivity through the SNAP-IV assessment, proposed by Mattos and collaborators (2006);
- Do not present visual or hearing disorders, heart disease, orthopedic dysfunction or behavioral disorders (according to medical assessment throughout the study)

Participants were divided into two groups in a random and random manner (casual/like a draw), using the software K_o_n_k_u_r_i_© for this purpose, as follows: Control Group (CG) – Composed of 10 children of both sexes who did not perform the Neuropsychopedagogical Intervention (NPpI), Experimental Group (EG) – Composed of 10 children of both sexes who performed the NPpI.

3.3 Intervention Procedures

The Neuropsychopedagogical Intervention with the Magic Cube was structured into 12 sessions of 15 minutes each, conducted by the classroom teacher, who was previously trained by the research team to apply the activity in a standardized manner. The sessions took place in the regular classroom environment, ensuring that students remained familiar with their learning context.

The teacher's training included detailed instructions on the intervention methodology, covering the introduction to the cube, an explanation of the solving algorithms, and guidance on conducting activities with the students. During the sessions, the teacher followed a predefined protocol, starting with the presentation of the cube's parts, its movements, and the logic behind the layer-by-layer solving method. Each session followed a structured sequence:

a) Introduction and Review – Recap of previously covered concepts and reinforcement of already taught movements and algorithms;
b) Guided Demonstration – A detailed explanation of the specific step to be worked on, accompanied by a practical demonstration by the teacher;
c) Supervised Practice – Students manipulated the cube following the instructions in the manual, under the teacher's supervision. The teacher intervened when necessary to ensure the correct application of the algorithms;

d) Closure and Adjustments – Review of common mistakes and guidance on the next steps.

Throughout the sessions, the students' progress was closely monitored by the teacher, who recorded observations regarding movement execution, adherence to the manual's instructions, and the need for additional support. The main focus of the intervention was the accurate application of algorithms, ensuring that students followed the logical steps of the cube-solving process without skipping any stage.

At the beginning of each new session, the teacher briefly reviewed previous content to reinforce concept retention and ensure a gradual progression in the students' learning process. The introduction of the cube's layers followed a sequential approach, respecting the students' assimilation time. Initially, students were guided through familiarization with the cube's pieces and the solving of the first layer. Subsequently, they progressed to the next layers, with a continuous emphasis on patience and careful observation of the movements.

3.4 Assessment Procedures Post-Neuropsychopedagogical Intervention

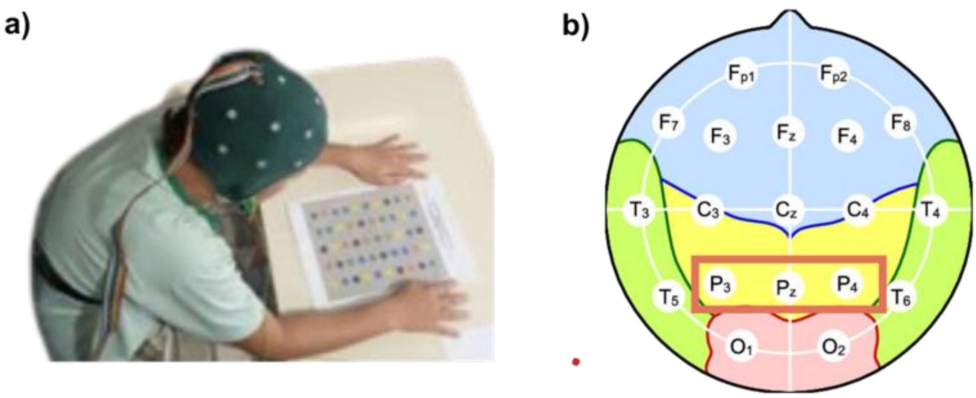
The Rapid Automatized Naming (RAN) test is a continuous measure of sequential naming speed for common stimuli, specifically assessing how quickly an individual can verbally identify a series of basic symbols. The test consists of subtests for naming colors, digits, letters, and objects. In the present study, only the color-naming subtest was used (Peng *et al.*, 2017). This subtest included the colors green, red, yellow, black, and blue, presented in a randomized sequence. Before testing, it was ensured that each participant could correctly recognize all the colors used in the assessment. The evaluation took place in a quiet, well-lit room within the school environment, where participants sat comfortably with their feet flat on the floor; if necessary, a footrest was provided for additional support. Participants were instructed to name the colors as quickly and accurately as possible while being allowed to point at the colors, ensuring they did not remove the test sheet from the table.

Simultaneously, electroencephalographic (EEG) signals were recorded throughout the execution of the RAN task to analyze brain activity patterns associated with cognitive processing (figure 1a). EEG data were collected using 19 electrodes positioned according to the international 10/20 system (FP1, FP2, F7, F8, F3, F4, T3, T4, C3, C4, T5, T6, P3, P4, O1, O2, FZ, CZ, and PZ). The Theta/Alpha Ratio (TAR) was computed using fixed frequency bands (4–7.5 Hz for theta, 8–12 Hz for alpha, and 13.5–25 Hz for beta).

For Theta/Alpha Ratio (TAR) analysis, EEG signals were extracted from electrodes PZ, P3, and P4 (Figure 1b), which correspond to a central region for visuomotor integration and cognitive processing. The analyzed EEG segment specifically corresponded to the naming period between the 16th and 30th circles, ensuring that the extracted spectral power patterns reflected active cognitive processing during the task execution.

This methodological approach allowed for the simultaneous assessment of naming speed and neural efficiency, providing a more comprehensive understanding of the cognitive mechanisms underlying executive function improvements post-neuropsychopedagogical intervention.

Figure 1: Experimental Procedure and Electrode Positions



a) Illustration of the experimental procedure, where the participant performs the Rapid Automatized Naming (RAN) task while EEG data is recorded; b) Diagram of the electrode positions used for EEG recording, following the international 10/20 system, with emphasis on the parietal electrodes (P3, PZ, P4) used for the Theta/Alpha Ratio analysis.

4. Results and Discussion

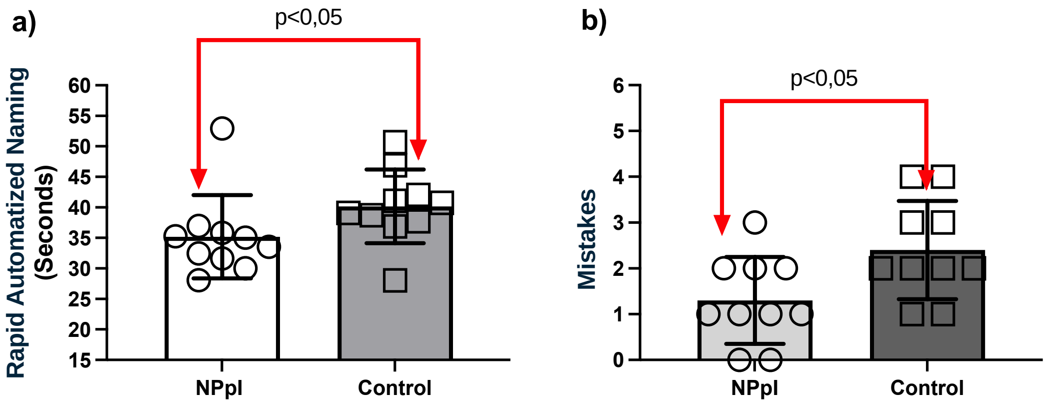
The minimum and maximum performance times for the NPpI group ranged from 28.06 to 52.94 seconds, compared to the Control group, which ranged from 28.04 to 50.69 seconds. The NPpI group achieved a faster mean test time of 35.18 seconds, while the Control group had a mean time of 40.19 seconds, demonstrating the NPpI group's superior ability to name the stimuli more quickly. Variability in performance, as measured by the standard deviation, was slightly higher in the NPpI group (6.823 seconds) compared to the Control group (6.034 seconds).

When evaluating the coefficient of variation, which reflects the relative dispersion of times as a percentage of the mean, the NPpI group showed a value of 19.40%, while the Control group presented a lower value of 15.01%, indicating greater individual variability within the NPpI group despite their better mean performance.

In summary, participants in the NPpI group were consistently faster on the Rapid Automatized Naming task compared to those in the Control group. A statistical comparison using the Mann-Whitney test confirmed a significant difference between the groups (P = 0.0232), underscoring the superior performance of the NPpI group and highlighting the effectiveness of the intervention (Figure 2a).

Still regarding performance in the RAN test, when analyzed in terms of the number of errors (figure 2b) made during the task, the NPpI group had a minimum error count of 0 and a maximum of 3, while the Control group ranged from 1 to 4 errors, indicating that the NPpI group exhibited a smaller range of errors. The mean number of errors in the NPpI group was 1.30, compared to 2.40 in the Control group, showing that participants in the NPpI group made fewer errors than those in the Control group. The standard deviation, reflecting data variation relative to the mean, was 0.9487 in the NPpI group and 1.075 in the Control group, indicating slightly greater dispersion in the Control group's data. The coefficient of variation, which expresses relative dispersion as a percentage, was 72.98% in the NPpI group and 44.79% in the Control group, showing that, although the NPpI group had fewer errors on average, there was greater variability among participants. A comparison between the two groups, conducted using the Mann-Whitney statistical test, identified a significant difference (P = 0.0415). This result demonstrates that the experimental group achieved superior performance in the test, highlighting the positive effects of the applied NPpI intervention.

Figure 2: Performance of participants in the Rapid Automatized Naming test

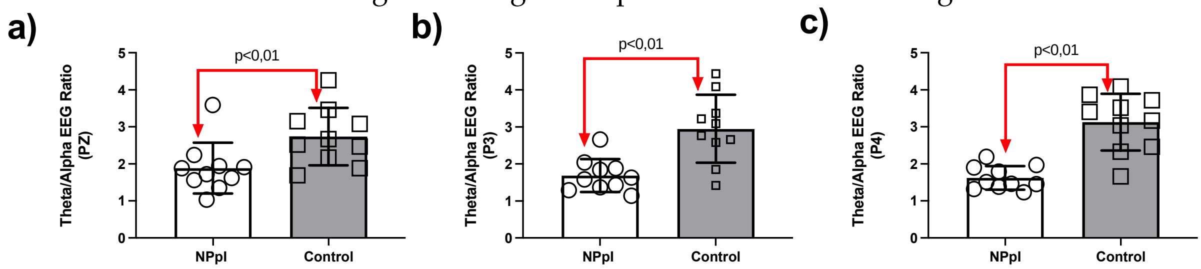


a) Task execution time, showing that the NPpI group had significantly shorter times ($p < 0.05$) compared to the Control group. b) Number of errors made during the task, indicating that the NPpI group exhibited a significantly lower number of errors ($p < 0.05$) compared to the Control group. The red line highlights the statistical comparison between the groups. Data are expressed as mean and standard deviation.

Upon analyzing the data derived from the recording of cortical electrical patterns, it is evident that, in the three electrodes located in the parietal region (PZ, P3, and P4), the Theta/Alpha ratio values show marked differences between the NPpI and Control groups during the Automated Naming Test, both in terms of amplitude (minimum and maximum values) and mean values. In electrode PZ (Figure 3a), the NPpI group registered values ranging from 1.030 (minimum) to 3.590 (maximum), with a mean of 1.884 and a standard deviation of 0.6878. In contrast, the Control group exhibited a range from 1.690 to 4.260, with a mean of 2.735 and a standard deviation of 0.7750. This difference in the mean represents an approximate increase of 45.2% ($p < 0.01$) in the Control group relative to the NPpI group. Regarding electrode P3 (Figure 3b), the NPpI group showed values between 1.140 (minimum) and 2.660 (maximum), with a mean of 1.686 and a standard deviation of 0.4435, while the Control group displayed values ranging from 1.420 to 4.440, reaching a mean of 2.949 and a standard deviation of 0.9185. This discrepancy results in an approximate increase of 74.9% ($p < 0.01$) in the mean value of the Control group compared to the NPpI group. Finally, with regard to electrode P4 (Figure 3c), the NPpI group's records varied from 1.230 (minimum) to 2.190 (maximum), with a mean of 1.620 and a standard deviation of 0.3199; in contrast, the Control group presented a range from 1.660 to 4.090, with a mean of 3.126 and a standard deviation of 0.7675. In this case, the Control group's mean was approximately 93.0% ($p < 0.01$) higher than that of the NPpI group.

Therefore, the analysis of the cortical electrical pattern recordings reveals that, across all studied electrodes, the mean Theta/Alpha ratio values are significantly higher in the Control group than in the NPpI group. This difference is observed not only in the means but also in the amplitude of the minimum and maximum values recorded, which may indicate important variations in cortical activity among the children during the test. Moreover, it is noteworthy that the expected value for absolute power, measured in μV^2, typically ranges between 1 and 2 μV^2.

Figure 3: Cortical Theta/Alpha Ratio Values in the Parietal Region during the Rapid Automatized Naming test



a) Electrode Pz – (NPpI group: 1.884 ± 0.6878 - Control group: 2.735 ± 0.7750); b) Electrode P3 – (NPpI group: 1.686 ± 0.4435 - Control group: 2.949 ± 0.9185) ; c) Electrode P4 – (NPpI group: 1.620 ± 0.3199 - Control group: 3.126 ± 0.7675). The red line in the figure indicates the statistical comparison between the groups performed using the t-test.

The results obtained in the present study after the intervention with the Rubik's Cube (NPpI) demonstrated significant improvements in participants' working memory, as evidenced by enhanced performance in the Rapid Automatized Naming (RAN) task. These findings suggest that NPpI, by stimulating executive functions, promoted an increase in the ability to maintain and manipulate information. This pattern of results aligns with previous studies that observed improvements in working memory following cognitive training interventions (Banales *et al.*, 2015; Etherton *et al.*, 2019; Peng *et al.*, 2017; Gashaj *et al.*, 2021).

It is important to highlight that studies have shown that executive function training through the use of the Rubik's Cube can lead to significant improvements in cognitive skills, such as inhibitory control, working memory, and cognitive flexibility. For instance, research conducted by Campello (2023), Montuori *et al.* (2023), and Singh *et al.* (2024) demonstrated that individuals who underwent training programs with the

Rubik's Cube exhibited notable gains in executive function efficiency, reflected in faster response times and fewer errors in standardized cognitive tasks.

Additionally, the improvements observed in the NPpI group were not limited to processing speed but also extended to task execution accuracy. The reduction in the number of errors, although accompanied by greater relative variability among participants, indicates that the intervention may be modulating not only speed but also the cognitive strategies used during the execution of challenging tasks (Vita-Barrull *et al.*, 2023). This reduction in errors is particularly relevant, as it suggests that Rubik's Cube training may contribute to better cognitive resource management and optimization of attentional processes, reducing the likelihood of distractions and processing lapses (Commodari *et al.*, 2024; Rosen *et al.*, 2025; Träff *et al.*, 2025).

Thus, our results reinforce the effectiveness of Rubik's Cube training as a strategy for enhancing executive functions (Singh *et al.*, 2024). They not only support the existing literature but also expand the understanding of the mechanisms by which interventions based on playful and challenging activities can positively impact cognitive performance (Cardoso *et al.*, 2024, 2025). These findings suggest that such interventions may be particularly useful in educational and clinical settings, paving the way for future research exploring the underlying neurobiological mechanisms and potential practical applications of Rubik's Cube training in diverse populations (Campello, 2023; Campello *et al.*, 2024).

Beyond the behavioral gains evidenced by faster response times and fewer errors in the Rapid Automatized Naming (RAN) task, our findings point to significant changes in cortical electrical patterns, particularly in the parietal region, which corroborate and deepen the understanding of the mechanisms underlying the executive function improvements induced by Rubik's Cube training (Rasmussen *et al.*, 2024; Saricaoglu *et al.*, 2025).

Specifically, electrophysiological recordings demonstrated that the Theta/Alpha ratio values in electrodes located in the parietal region (PZ, P3, and P4) were significantly lower in the intervention group (NPpI) compared to the control group. This reduction in the Theta/Alpha ratio can be interpreted as a sign of greater neural efficiency, as a decrease in theta activity relative to alpha activity has been associated with more optimized cognitive processing states and reduced cognitive effort during task execution (Trammell *et al.*, 2017; Cai *et al.*, 2021; Magosso & Borra, 2024). A Theta/Alpha ratio between 1 and 2 μV^2 has been associated with more efficient information integration and superior performance in tasks requiring sustained attention and working memory, fundamental skills for problem-solving and decision-making (Liu *et al.*, 2016; Cellier *et al.*, 2021; Hofstee *et al.*, 2024).

The literature suggests that executive function training, especially through activities that combine cognitive challenges with playful aspects—such as solving the Rubik's Cube—can induce neuroplastic processes that lead to adjustments in functional connectivity and neural organization (Enns *et al.*, 2024). These processes, which include synaptic remodeling and neural circuit optimization, may result in a reorganization of cortical activity, particularly in parietal and prefrontal regions, which are closely involved in the processing and mental manipulation of information required in working memory tasks, such as the rapid automatized naming task (Cona *et al.*, 2024; Hartmann & Dumureau, 2024; Otstavnov *et al.*, 2024). Thus, the observed modulation of the Theta/Alpha ratio may reflect a functional reconfiguration that fosters a more adaptive and efficient brain state, enabling faster and more precise cognitive processing (Frelih *et al.*, 2024; Wei *et al.*, 2024; Tan *et al.*, 2024).

Moreover, the interaction between attentional processes and sensorimotor integration, mediated by parietal areas, is essential for performing tasks that require rapid adaptation and response (Bai *et al.*, 2021; Wei *et al.*, 2024; Fornia *et al.*, 2024). The Rubik's Cube intervention, by requiring coordinated movements, problem-solving, and constant strategy updates, appears to enhance this interaction, facilitating the functional reorganization of neural networks (Maurer & Roebers, 2021; Chanpirom *et al.*, 2021; Khatib *et al.*, 2022; Meijer *et al.*, 2025). This hypothesis is supported by studies that reported improvements in connectivity between the prefrontal cortex and parietal regions following intensive cognitive training, indicating that such interventions may promote better communication between areas responsible for task execution and monitoring (van Balkom *et al.*, 2020; Lee *et al.*, 2022; Schwarze *et al.*, 2023; Badia-Aguarón *et al.*, 2024).

By connecting behavioral data with changes in cortical electrical patterns, our study not only reinforces the effectiveness of Rubik's Cube training in enhancing executive functions but also highlights its ability to induce measurable changes in brain activity. These findings suggest that such interventions may be particularly beneficial in contexts where optimizing cognitive processes is desired, such as in educational and clinical settings, and encourage the investigation of innovative strategies for cognitive training (Cardoso *et al.*, 2024, 2025; Rivella *et al.*, 2024).

Finally, the robustness of the results, evidenced by both behavioral indicators and electrophysiological parameters, supports the hypothesis that executive function training can generate significant neuroplastic effects. These effects not only enhance neural processing efficiency but also promote greater cognitive resilience and adaptability, fundamental aspects for performing complex tasks and developing skills that extend beyond the specific training context. Such evidence opens pathways for future investigations exploring, in greater depth, the underlying neurobiological mechanisms and the clinical applicability of interventions based on playful and cognitively demanding activities.

5. Recommendations

This study highlights the potential of the Neuropsychopedagogical Intervention (NPpI) using the Rubik's Cube to enhance executive functions and improve neural efficiency.

However, certain limitations should be addressed in future research. One of the primary limitations is the small sample size (n = 20), which reduces the generalizability of the findings. It is recommended that future studies include larger and more diverse samples to validate the results and better understand the intervention's impact across broader populations.

Additionally, the intervention duration in this study was limited to 12 sessions of 15 minutes each. While significant improvements were observed, extending the intervention period may further enhance the cognitive and neural benefits of NPpI. Longer-term studies are needed to assess the sustainability of these improvements and to determine whether prolonged exposure to the intervention results in greater and more robust effects.

Moreover, future research should consider expanding the scope to include populations with specific learning or attention difficulties to explore the applicability of NPpI contexts. Incorporating advanced neuroimaging techniques to investigate the underlying neuroplastic mechanisms would provide deeper insights into the processes driving these improvements.

Finally, given the intervention's accessibility and low cost, its integration into educational and clinical programs holds promise as a practical tool for enhancing cognitive development. Researchers should explore how the Rubik's Cube intervention can be scaled and adapted for different contexts to maximize its potential benefits.

6. Conclusion

The results of this study demonstrate the effectiveness of the Neuropsychopedagogical Intervention (NPpI) using the Rubik's Cube in enhancing executive functions and neural efficiency in children aged 7 to 9 years. Participants who underwent the intervention exhibited significant improvements in performance on the Rapid Automatized Naming (RAN) task, with faster response times and fewer errors compared to the control group. Additionally, lower Theta/Alpha ratios in the parietal region were observed in the NPpI group, indicating optimized neural activity and greater cognitive efficiency during task execution.

These findings align with previous research suggesting that structured and playful cognitive interventions can induce meaningful neuroplastic changes, contributing to improvements in working memory, inhibitory control, and cognitive flexibility. The Rubik's Cube intervention has proven to be a practical, low-cost tool for fostering cognitive development, making it a promising strategy for educational and clinical applications.

Despite these encouraging results, the study's limitations, including a small sample size and a relatively short intervention duration, highlight the need for further research. Future studies should explore the long-term effects of the intervention, include larger and more diverse populations, and investigate the underlying neurobiological mechanisms using advanced methodologies.

In conclusion, the NPpI demonstrates significant potential as a tool for cognitive enhancement, offering a scalable and accessible approach to improving executive functions in children. Its integration into educational programs could have broad implications for fostering cognitive resilience, adaptability, and overall academic success.

Acknowledgements

The authors would like to express their sincere gratitude to the Municipal Department of Education of Brusque, Santa Catarina, Brazil, for their invaluable support and collaboration throughout this study. The partnership established through the Technical-Scientific Cooperation Agreement was fundamental in facilitating the development of this research, providing access to participants, and ensuring the smooth implementation of the intervention within the school environment. Your commitment to advancing education and fostering innovative research initiatives has greatly contributed to the success of this project.

About the Author(s)

Fabrício Bruno holds a degree in Physical Education (Castelo Branco University), a master's in Human Motor Science (Castelo Branco University), and a PhD in Biological Sciences (Biophysics) from the Federal University of Rio de Janeiro. He is the Coordinator of the Postgraduate Course in Neuropsychopedagogy at CENSUPEG College, Leader of the Laboratory of Educational Innovations and Neuropsychopedagogical Studies (LIEENP-CENSUPEG), Visiting Professor at the Federal University of Rio de Janeiro, Associate Researcher at the National Science Network for Education, and Director of Research and Innovation at the Science and Cognition Organization.

Email: fabricio@censupeg.com.br.

Alfred Sholl-Franco biologist, neuroscientist, and neuropsychopedagogue, with a Master's and Ph.D. in Biological Sciences (Biophysics). Associate Professor I at UFRJ (IBCCF, Neurobiology Program), Coordinator of the Center for Scientific Dissemination and Teaching of Neurosciences (NuDCEN/IBCCF), and Associate Researcher at the Laboratory of Neurogenesis (IBCCF, UFRJ). His research focuses on nervous system development, learning processes, learning disorders, literacy, and inclusion. He coordinates the NEUROEDUC and Neuroimmunology research groups (CNPq) and is a member of SBNeC, SfN, IMBES, and CpE. Founder and Editor-in-Chief of *Ciências e Cognição*, he is also a faculty member in UFRJ's Graduate Programs (Biological Sciences – Biophysics, PROFICIÊNCIAS, and MP-EGeD) and UFF's Graduate Program in Diversity and Inclusion and researcher at the Laboratory of Educational Innovations and Neuropsychopedagogical Studies - Faculdade CENSUPEG.

Email: asholl@biof.ufrj.br

Érica Garcia Silveira Gonçalves holds a degree in Pedagogy from Universidade Estácio de Sá (2017) and a Teaching Certification from Instituto de Educação Prof. Moisés Henrique dos Santos (2001). Currently a permanent teacher at the Municipal Government of Brusque, with experience in Education, focusing on Technology and Educational Robotics. Creator of the Magicubo project, implemented in the municipal school network of Brusque-SC.

Filipi Prado Grimm completed his high school education at Escola de Educação Básica João XXIII, Brazil (2014). Currently, he works as a Monitor 3 for the Municipal Government of Brusque, Brazil, focusing on Technology and Educational Robotics, specifically in the Magicubo project, implemented in the municipal school network of Brusque-SC.

Everton Odisi holds a bachelor's degree in Production Engineering from the Centro Universitário de Brusque – UNIFEBE. Currently, he works as a Technology Education Teacher for the Municipal Government, specializing in Educational Robotics and actively contributing to the Magicubo project in the municipal school network of Brusque-SC.

Aliny Carvalho Dematté - M.D. from the Federal University of Rio de Janeiro (UFRJ) (2016–2023) and Ph.D. candidate in Biophysics/Neurobiology at the Carlos Chagas Filho Institute of Biophysics (IBCCF/UFRJ) through the MD-PhD program. Research focuses on learning disorders, Attention Deficit Hyperactivity Disorder (ADHD), perceptual-motor development, visuomotor integration, and neuroeducation. Associate researcher at the Center for Scientific Dissemination and Teaching of Neurosciences (NUDCEN/IBCCF/UFRJ) and researcher at the Laboratory of Educational Innovations and Neuropsychopedagogical Studies - Faculdade CENSUPEG.
Email: alinycarvalho@biof.ufrj.br

João Vitor Galo Esteves - Medical degree from the Federal University of Rio de Janeiro (FM/UFRJ, 2020) with a specialization in Higher Education Teaching (CENSUPEG, 2020). Currently a Ph.D. candidate in Biophysics/Neurobiology at the Carlos Chagas Filho Institute of Biophysics (IBCCF/UFRJ) through the MD-PhD program. National Coordinator of the Brazilian Brain Bee (Olimpíada Brasileira de Neurociências), associate researcher at the Center for Scientific Dissemination and Teaching of Neurosciences (NUDCEN/IBCCF/UFRJ), and researcher at the Laboratory of Educational Innovations and Neuropsychopedagogical Studies - Faculdade CENSUPEG.
Email: jvitorgallo@biof.ufrj.br

Washington Adolfo Batista - Master's degree in Mental Health from IPUB/UFRJ. Specialist in Sports Training (UFRJ), Education and Psychomotor Reeducation (UERJ), Neuroscience Applied to Learning (IPUB/UFRJ), Teaching in Basic Education – Physical Education (PRD/CPII), and Clinical Neuropsychopedagogy (CENSUPEG). Holds a degree in Physical Education from Universidade Salgado de Oliveira and a degree in Pedagogy from Universidade do Estado do Rio de Janeiro (UERJ,) researcher at the Laboratory of Educational Innovations and Neuropsychopedagogical Studies – Faculdade CENSUPEG.

Email: washington.batista@censupeg.com.br
Filipe M. Bonone graduated in Physiotherapy from Universidade Gama Filho (2000), received a Master's in Experimental Neurology from Universidade Federal de São Paulo (2004), and a Ph.D. in Neurology/Neurosciences from Universidade Federal de São Paulo (2008). Director of the Faculdade CENSUPEG of Medicine and researcher at the Laboratory of Educational Innovations and Neuropsychopedagogical Studies - Faculdade CENSUPEG.
Email: filipe.bonone@censupeg.com.br

References

Apšvalka, D., Ferreira, C. S., Schmitz, T. W., Rowe, J. B., & Anderson, M. C. (2022). Dynamic targeting enables domain-general inhibitory control over action and thought by the prefrontal cortex. *Nature Communications, 13*, 274. https://doi.org/10.1038/s41467-021-27926-w

Badia-Aguarón, T., Royuela-Colomer, E., Pera-Guardiola, V., Vergés-Balasch, P., Cebolla, A., Luciano, J. V., Soler, J., Feliu-Soler, A., & Huguet Miguel, A. (2024). Combining mindfulness and cognitive training in children with attention deficit hyperactivity disorder: Study protocol of a pilot randomized controlled trial (the NeuroMind study). *Frontiers in Psychology, 15*. https://doi.org/10.3389/fpsyg.2024.1291198

Bai, S., Liu, W., & Guan, Y. (2021). The visuospatial and sensorimotor functions of the posterior parietal cortex in drawing tasks: A review. *Frontiers in Aging Neuroscience, 13*. https://doi.org/10.3389/fnagi.2021.717002

Banales, E., Kohnen, S., & McArthur, G. (2015). O treinamento da memória de trabalho verbal pode melhorar a leitura? Neuropsicologia Cognitiva, 32(3–4), 104–132. https://doi.org/10.1080/02643294.2015.1014331

Bombonato, C., Del Lucchese, B., Ruffini, C., Di Lieto, M. C., Brovedani, P., Sgandurra, G., Cioni, G., & Pecini, C. (2024). Far transfer effects of trainings on executive functions in neurodevelopmental disorders: A systematic review and metanalysis. *Neuropsychology Review, 34*, 98–133. https://doi.org/10.1007/s11065-022-09574-z

Boutzoukas, E. M., O'Shea, A., Albizu, A., Evangelista, N. D., Hausman, H. K., Kraft, J. N., Van Etten, E. J., Bharadwaj, P. K., Smith, S. G., Song, H., Porges, E. C., Hishaw, A., DeKosky, S. T., Wu, S. S., Marsiske, M., Alexander, G. E., Cohen, R., & Woods, A. J. (2021). Frontal White Matter Hyperintensities and Executive Functioning Performance in Older Adults. *Frontiers in aging neuroscience*, *13*. https://doi.org/10.3389/fnagi.2021.672535

Cai, D., Deng, M., Yu, J., Nan, W., & Leung, A. W. S. (2021). The relationship of resting-state EEG oscillations to executive functions in middle childhood. *International Journal of Psychophysiology, 164*, 64–70. https://doi.org/10.1016/j.ijpsycho.2021.02.021

Campelo, J. P. M. (2023). *Jogos matemáticos para desenvolvimento cognitivo: Uma visão neuropsicopedagógica* (Dissertação de mestrado). Universidade Federal do Piauí.

Campelo, J. P. M., Cardoso, F. B., & Cunha, K. M. (2023). Jogos lógicos para estímulo à cognição matemática: Interações com as neurociências aplicadas à aprendizagem. *Anais da XI Bienal da Matemática*, 203–206. Sociedade Brasileira de Matemática. https://sbm.org.br

Cao, C., Wen, W., Chen, A., Wang, S., Xu, G., Niu, C., & Song, J. (2023). Neuropsychological Alterations of Prolactinomas' Cognitive Flexibility in Task Switching. *Brain Sciences*, *13*(1), 82. https://doi.org/10.3390/brainsci13010082

Capodieci, A., Ruffini, C., Frascari, A., Rivella, C., Bombonato, C., Giaccherini, S., Scali, V., Luccherino, L., Viterbori, P., Traverso, L., Usai, M. C., Marzocchi, G. M., & Pecini, C. (2023). Executive functions in children with specific learning disorders: Shedding light on a complex profile through teleassessment. *Research in Developmental Disabilities, 142*. https://doi.org/10.1016/j.ridd.2023.104621

Cardoso, F. B., Loureiro, V. D. S., Souza, S., Pinheiro, J., Fulle, A. , Russo, R. M. T., Esteves, J. V. G., Carvalho, A. D. S., & Sholl-Franco, A. (2021). The Effects of Neuropsychopedagogical Intervention on Children with Learning Difficulties. *American Journal of Educational Research*, *9*(11), 673-677. DOI: 10.12691/education-9-11-3

Cardoso, F., Braga, L., Loureiro, V., Bonone, F., Souza, S., & Sholl-Franco, A. (2024). Neuropsychopedagogical motor intervention program strengthening inhibitory control, working memory, and language abilities in post-COVID-19 school returnees. *Journal of Education and Training Studies,* 12(3). https://doi.org/10.11114/jets.v12i3.6789

Cardoso, F. B., Braga, L., Bonone, F. M., Algarve, F., Defreyn, E., Justi, N. da S., Ferreira, R. A., Ferreira, J. K. D. S., Souza, F., & Sholl-Franco, A. (2025). Impact of a neuropsychopedagogical motor program on executive functions and language skills in preschoolers. *SCIREA Journal of Education, 10*(1), 1–19. https://doi.org/10.54647/education880565

Cellier, D., Riddle, J., Petersen, I., & Hwang, K. (2021). The development of theta and alpha neural oscillations from ages 3 to 24 years. *Developmental cognitive neuroscience*, *50*. https://doi.org/10.1016/j.dcn.2021.100969

Chanpirom, R., Lersilp, S., Putthinoi, S., & Chaimaha, N. (2021). Relationship between Cognitive Performance and Visual Motor Integration in Preschool Children in A Community: A Pilot Study. *Journal of Occupational Therapy, Schools, & Early Intervention*, *15*(3), 231–243. https://doi.org/10.1080/19411243.2021.1975602

Charlebois-Poirier, A.-R., Davoudi, S., Lalancette, È., Knoth, I. S., & Lippé, S. (2025). The level of cognitive functioning in school-aged children is predicted by resting EEG Directed Phase Lag Index. *Scientific Reports, 15*, 1531. https://doi.org/10.1038/s41598-025-85635-6

Clements, G. M., Gyurkovics, M., Low, K. A., Beck, D. M., Fabiani, M., & Gratton, G. (2022). Dynamics of alpha suppression and enhancement may be related to resource competition in cross-modal cortical regions. *NeuroImage*, *252*. https://doi.org/10.1016/j.neuroimage.2022.119048

Cole, M. W. (2024). Cognitive flexibility as the shifting of brain network flows by flexible neural representations. *Current Opinion in Behavioral Sciences*, *57*, 101384. https://doi.org/10.1016/j.cobeha.2024.101384

Commodari, E., Sole, J., Guarnera, M., & La Rosa, V. L. (2024). Mental imagery in education: What impact on the relationships with visuospatial processing and school performance in junior high school students? *Thinking Skills and Creativity, 54*, 101667. https://doi.org/10.1016/j.tsc.2024.101667

Cona, G., Wiener, M., Allegrini, F., & Scarpazza, C. (2024). Gradient Organization of Space, Time, and Numbers in the Brain: A Meta-analysis of Neuroimaging Studies. *Neuropsychology review*, *34*(3), 721–737. https://doi.org/10.1007/s11065-023-09609-z

Cremone, A, Mcdermott, J. M., & Spencer, R. M. C. (2017). Naps Enhance Executive Attention in Preschool-Aged Children. *J Pediatr Psychol, 42* (8), 837-845. https://doi.org/10.1093/jpepsy/jsx048

Diamond, A., & Ling, D. S. (2016). Conclusions about interventions, programs, and approaches for improving executive functions that appear justified and those that, despite much hype, do not. *Developmental Cognitive Neuroscience, 18*, 34–48. https://doi.org/10.1016/j.dcn.2015.11.005

Diamond, A., Lee, C., Senften, P., Lam, A., & Abbott, D. (2019). Randomized control trial of *Tools of the Mind*: Marked benefits to kindergarten children and their teachers. *PLoS ONE, 14*(9). https://doi.org/10.1371/journal.pone.0222447

Domic-Siede, M., Irani, M., Valdés, J., Perrone-Bertolotti, M., & Ossandón, T. (2021). Theta activity from frontopolar cortex, mid-cingulate cortex, and anterior cingulate cortex shows different roles in cognitive planning performance. *NeuroImage, 226*. https://doi.org/10.1016/j.neuroimage.2020.117557

dos Anjos, P. G., de Souza, L. N., Paulino, J. de A., da Silva, M. D., de Oliveira, L. da C., da Cruz, I. K. M., da Silva, E. C., & Liberal, S. da S. (2024). The importance of neuropsychopedagogy in the teaching and learning process of students with disabilities in basic education. *Caderno Pedagógico*, *21*(2), e2696. https://doi.org/10.54033/cadpedv21n2-028

Draheim, C., Pak, R., Draheim, A. A., & Engle, R. W. (2022). The role of attention control in complex real-world tasks. *Psychonomic Bulletin & Review, 29*, 1143–1197. https://doi.org/10.3758/s13423-021-02052-2

Dwyer C. P. (2023). An Evaluative Review of Barriers to Critical Thinking in Educational and Real-World Settings. *Journal of Intelligence*, *11*(6), 105. https://doi.org/10.3390/jintelligence11060105

Eng, C. M., Pocsai, M., Fulton, V. E., Moron, S. P., Thiessen, E. D., & Fisher, A. V. (2022). Longitudinal investigation of executive function development employing task-based, teacher reports, and fNIRS multimethodology in 4- to 5-year-old children. *Developmental science*, *25*(6). https://doi.org/10.1111/desc.13328

Enns, JT, Kozik, P., & Dudarev, V. (2024). Exercícios cognitivamente envolventes predizem o funcionamento executivo em tarefas de laboratório. *Current Issues in Sport Science (CISS)* , *9* (1). https://doi.org/10.36950/2024.9ciss007

Etherton, JL, Oberle, CD, Rhoton, J., & Ney, A. (2019). Efeitos do treinamento de memória de trabalho Cogmed no desempenho cognitivo. *Psychological Research, 83*(7), 1506–1518. 10.1007/s00426-018-1012-9

Etokabeka, E. (2024). Supporting the development of executive function skills through structured play: A qualitative study of South African preschool teachers. *Early Childhood Education Journal*. https://doi.org/10.1007/s10643-024-01827-1

Florio, T. M. (2025). Emergent Aspects of the Integration of Sensory and Motor Functions. *Brain Sciences*, *15*(2), 162. https://doi.org/10.3390/brainsci15020162

Fornia, L., Leonetti, A., Puglisi, G., Rossi, M., Viganò, L., Della Santa, B., Simone, L., Bello, L., & Cerri, G. (2024). The parietal architecture binding cognition to sensorimotor integration: a multimodal causal study. *Brain: a journal of neurology*, *147*(1), 297–310. https://doi.org/10.1093/brain/awad316

Frelih, T., Matkovič, A., Mlinarič, T., Bon, J., & Repovš, G. (2024). Modulation of aperiodic EEG activity provides a sensitive index of cognitive state changes during a working memory task. *eLife, 13*. https://doi.org/10.7554/eLife.101071.1

Friedman, N. P., & Robbins, T. W. (2022). The role of prefrontal cortex in cognitive control and executive function. *Neuropsychopharmacology : official publication of the American College of Neuropsychopharmacology*, *47*(1), 72–89. https://doi.org/10.1038/s41386-021-01132-0

Gashaj, V., Dapp, L. C., Trninic, D., & Roebers, C. M. (2021). The effect of video games, exergames and board games on executive functions in kindergarten and 2nd grade: An explorative longitudinal study. *Trends in Neuroscience and Education, 25*, 100162. https://doi.org/10.1016/j.tine.2021.100162

Giovannetti, E. A., & Rancz, E. (2024). Behind mouse eyes: The function and control of eye movements in mice. *Neuroscience & Biobehavioral Reviews, 161*, 105671. https://doi.org/10.1016/j.neubiorev.2024.105671

Graziani, D., Capodieci, A., Casalini, C., Giaccherini, S., Scali, V., Luccherino, L., & Pecini, C. (2024). Training rapid automatized naming in children with developmental Dyslexia. *Child Neuropsychology*, 1–27. https://doi.org/10.1080/09297049.2024.2414019

Grehs, B. D. M. S., Guerin, C. S., Loureiro, V. D. S., Souza, S. P. D., & Cardoso, F. B. (2024). Learning strategies: A resource for clinical neuropsychopedagogical intervention. *International Journal of Psychological and Brain Sciences, 9*(2), 14–20. https://doi.org/10.11648/j.ijpbs.20240902.11

Hartmann, M., & Dumureau, M. (2024). Anodal high-definition transcranial direct current stimulation over the left (but not right) parietal cortex facilitates mental arithmetic. *Journal of Cognitive Enhancement.* https://doi.org/10.1007/s41465-024-00314-0

Hertrich, I., Dietrich, S., Blum, C., & Ackermann, H. (2021). The Role of the Dorsolateral Prefrontal Cortex for Speech and Language Processing. *Frontiers in human neuroscience*, *15*, 645209. https://doi.org/10.3389/fnhum.2021.645209

Hofstee, M., Endendijk, J., Huijding, J., van der Velde, B., Vidal, J., & Deković, M. (2024). Maturational changes in frontal EEG alpha and theta activity from infancy into early childhood and the relation with self-regulation in boys and girls. *Developmental Cognitive Neuroscience, 70*. https://doi.org/10.1016/j.dcn.2024.101445

Hooge, I. T. C., Nuthmann, A., Nyström, M., Niehorster, D. C., Holleman, G. A., Andersson, R., & Hessels, R. S. (2025). The fundamentals of eye tracking part 2: From research question to operationalization. *Behavior Research Methods, 57*, 73. https://doi.org/10.3758/s13428-024-02590-2

Huang, H., Li, R., Qiao, X., Li, X., Li, Z., Chen, S., Yao, Y., Wang, F., Zhang, X., Lin, K., & Zhang, J. (2024). Attentional control influences habituation through modulation of connectivity patterns within the prefrontal cortex: Insights from stereo-EEG. *NeuroImage*, *294*, 120640. https://doi.org/10.1016/j.neuroimage.2024.120640

Ibbotson, P. (2023). The Development of Executive Function: Mechanisms of Change and Functional Pressures. *Journal of Cognition and Development*, *24*(2), 172–190. https://doi.org/10.1080/15248372.2022.2160719

Kazali, E. (2025). Executive functions in inductive and deductive reasoning. *Journal of Experimental Child Psychology, 252*. https://doi.org/10.1016/j.jecp.2024.106144

Khan, K., & Lal, P. (2023). Executive dysfunctions in different learning disabilities: A review. *Journal of Indian Association for Child and Adolescent Mental Health, 19*(2), 126–142. https://doi.org/10.1177/09731342231179614

Khatib, L., Li, Y., Geary, D., & Popov, V. (2022). Meta-analysis on the relation between visuomotor integration and academic achievement: Role of educational stage and disability. *Educational Research Review, 35*. https://doi.org/10.1016/j.edurev.2021.100412

Korda, Ž., Walcher, S., Körner, C., & Benedek, M. (2024). Internal coupling: Eye behavior coupled to visual imagery. *Neuroscience & Biobehavioral Reviews, 165*. https://doi.org/10.1016/j.neubiorev.2024.105855

Kostyrka-Allchorne, K., Wass, S. V., Yusuf, H., Rao, V., Bertini, C., & Sonuga-Barke, E. J. S. (2023). Inhibitory deficits and symptoms of attention-deficit hyperactivity disorder: How are they related to effortful control?. *The British journal of developmental psychology*, *41*(1), 50–65. https://doi.org/10.1111/bjdp.12432

Lambert, K., DiCarlo, C. F., & Rueter, D. (2025). Using games and activities to increase inhibitory control skills in kindergarten-aged children. *Early Childhood Education Journal*. https://doi.org/10.1007/s10643-024-01847-x

Lee, R., Kwak, S., Lee, D., & Chey, J. (2022). Cognitive control training enhances the integration of intrinsic functional networks in adolescents. *Frontiers in Human Neuroscience, 16*. https://doi.org/10.3389/fnhum.2022.859358

Lesser, R. P., Webber, W. R. S., & Miglioretti, D. L. (2024). Pan-cortical electrophysiologic changes underlying attention. *Scientific Reports, 14*, 2680. https://doi.org/10.1038/s41598-024-52717-w

Li, S., Rosen, M. C., Chang, S., David, S., & Freedman, D. J. (2023). Alterations of neural activity in the prefrontal cortex associated with deficits in working memory performance. *Frontiers in behavioral neuroscience, 17*. https://doi.org/10.3389/fnbeh.2023.1213435

Liu, ZX, Glizer, D., Tannock, R., & Woltering, S. (2016). Potência alfa do EEG durante a manutenção de informações na memória de trabalho em adultos com TDAH e sua plasticidade devido ao treinamento da memória de trabalho: Um ensaio clínico randomizado. *Neurofisiologia Clínica, 127*(2), 1307–1320. 10.1016/j.clinph.2015.10.032

Lo, H. K.-Y., Fong, T. K.-H., Cheung, T., Ngan, S.-T. J., Lui, W.-Y. V., Chan, W.-C., Wong, C. S.-M., Wong, T. K.-T., & Cheng, C. P.-W. (2024). Enhanced Cognition and Modulation of Brain Connectivity in Mild Neurocognitive Disorder: The Promise of Transcranial Pulse Stimulation. *Biomedicines*, *12*(9), 2081. https://doi.org/10.3390/biomedicines12092081

Loureiro, V. S., & Cardoso, F. B. (2022). The impact of emergency remote teaching on teachers' perceptions of learning difficulties in the context of neuropsychopedagogics. *Lurian Journal*, *3*(2), 25–33. https://doi.org/10.15826/Lurian.2022.3.2.2

Loureiro, V. da S., Souza, C. A. M. de, & Cardoso, F. B. (2022). Modelo de intervenção multicamadas: Uma proposta de atuação neuropsicopedagógica institucional. *Mundo Livre: Revista Multidisciplinar*, *8*(2), 63–86. Recuperado de https://periodicos.uff.br/mundolivre/article/view/55399

Loureiro, V. da S., Novaes, A. de O., & Cardoso, F. B. (2024). Percepções Docentes Sobre as Dificuldades de Aprendizagem: Aportes da Neuropsicopedagogia. *Revista De Ensino, Educação E Ciências Humanas*, *25*(1), 28–33. https://doi.org/10.17921/2447-8733.2024v25n1p28-33

Magosso, E., & Borra, D. (2024). The strength of anticipated distractors shapes EEG alpha and theta oscillations in a working memory task. *NeuroImage, 300*, 120835. https://doi.org/10.1016/j.neuroimage.2024.120835

Marshall, T., Farrar, A., Wilson, M., Taylor, J., George, P., Ghose, S. S., Cosgrove, J., & Patel, N. A. (2025). Mindfulness-Based Interventions in Schools: Assessing the Evidence Base. *Psychiatric services (Washington, D.C.)*, *76*(1), 49–60. https://doi.org/10.1176/appi.ps.20240027

Maurer, M. N., & Roebers, C. M. (2021). New insights into visual-motor integration exploring process measures during copying shapes. *Psychology of Sport and Exercise*, *55*, 101954. https://doi.org/10.1016/j.psychsport.2021.101954

Meijer, J. S., de Jonge, M. L., Leenen, S., van Beek, P. E., de Kort, E., Vugs, B., & Andriessen, P. (2025). From movement to mind: Early fine motor skills are associated with cognitive performance at school age in very preterm infants. *Early Human Development*, *201*. https://doi.org/10.1016/j.earlhumdev.2025.106197

Mendes, A. J., Galdo-Álvarez, S., Lema, A., Carvalho, S., & Leite, J. (2024). Transcranial Direct Current Stimulation Decreases P3 Amplitude and Inherent Delta Activity during a Waiting Impulsivity Paradigm: Crossover Study. *Brain sciences*, *14*(2), 168. https://doi.org/10.3390/brainsci14020168

Montuori, C., Pozzan, G., Padova, C., Ronconi, L., Vardanega, T., & Arfé, B. (2023). Combined Unplugged and Educational Robotics Training to Promote Computational Thinking and Cognitive Abilities in Preschoolers. *Education Sciences*, *13*(9), 858. https://doi.org/10.3390/educsci13090858

Morra, S., Howard, S. J., & Loaiza, V. M. (2025). Working Memory and Executive Functions: Theoretical Advances. *Journal of Cognition*, *8*(1): 15, pp. 1–6. https://doi.org/10.5334/joc.42

Nguyen, L., Murphy, K., & Andrews, G. (2019). Cognitive and neural plasticity in old age: A systematic review of evidence from executive functions cognitive training. *Ageing Research Reviews*, *53*, 100912. https://doi.org/10.1016/j.arr.2019.100912

Okur, M., & Aksoy, V. (2025). The Effect of a Working Memory Intervention Package on the Working Memory Performance of Primary School Students with Specific Learning Disabilities. *Journal of Intelligence*, *13*(2), 16. https://doi.org/10.3390/jintelligence13020016

Otstavnov, N., Nieto-Doval, C., Galli, G., & Feurra, M. (2024). Frontoparietal brain network plays a crucial role in working memory capacity during complex cognitive task. *eNeuro*, *11*(8), https://doi.org/10.1523/ENEURO.0394-23.2024

Paas, F., & van Merriënboer, J. J. (2020). Cognitive-load theory: Methods to manage working memory load in the learning of complex tasks. *Current Directions in Psychological Science*, *29*(4), 394-398. https://doi.org/10.1177/0963721420922183

Pedroso, R. V., Lima-Silva, A. E., Tarachuque, P. E., Fraga, F. J., & Stein, A. M. (2021). Efficacy of Physical Exercise on Cortical Activity Modulation in Mild Cognitive Impairment: A Systematic Review. *Archives of physical medicine and rehabilitation*, *102*(12), 2393–2401. https://doi.org/10.1016/j.apmr.2021.03.032

Peng, J., Mo, L., Huang, P., & Zhou, Y. (2017). Os efeitos do treinamento da memória de trabalho na melhoria da inteligência fluida de crianças durante a primeira infância. *Cognitive Development*, *43*, 224–234. https://psycnet.apa.org/doi/10.1016/j.cogdev.2017.05.006

Perez, V., Duque, A., Hidalgo, V., & Salvador, A. (2024). EEG frequency bands in subjective cognitive decline: A systematic review of resting state studies. *Biological Psychology, 191*, 108823. https://doi.org/10.1016/j.biopsycho.2024.108823

Perpiñà Martí, G., Sidera, F., Senar Morera, F., & Serrat Sellabona, E. (2023). Executive functions are important for academic achievement, but emotional intelligence too. *Scandinavian Journal of Psychology, 64*(5), 470–478. https://doi.org/10.1111/sjop.12907

Pradeep, K., Anbalagan, R. S., Thangavelu, A. P., Aswathy, S., Jisha, V. G., & Vaisakhi, V. S. (2024). Neuroeducation: Understanding neural dynamics in learning and teaching. *Frontiers in Education, 9*. https://doi.org/10.3389/feduc.2024.1437418

Rasmussen, T., Filmer, H. L., & Dux, P. E. (2024). On the role of prefrontal and parietal cortices in mind wandering and dynamic thought. *Cortex, 178*, 249–268. https://doi.org/10.1016/j.cortex.2024.06.017

Ritz, H., Leng, X., & Shenhav, A. (2022). Cognitive control as a multivariate optimization problem. *Journal of Cognitive Neuroscience, 34*(4), 569–591. https://doi.org/10.1162/jocn_a_01822

Rivella, C., Bombonato, C., Pecini, C., Frascari, A., & Viterbori, P. (2024). Improving executive functions at school. Integrating metacognitive exercise in class and computerized training at home to ensure training intensity and generalization. A feasibility pilot study. *British Journal of Educational Technology*, 55, 2719–2739. https://doi.org/10.1111/bjet.13470

Robledo-Castro, C., Hederich-Martínez, C., & Castillo-Ossa, L. F. (2023). Cognitive stimulation of executive functions through computational thinking. *Journal of Experimental Child Psychology, 235*, 105738. https://doi.org/10.1016/j.jecp.2023.105738

Rosen, M. L., Li, A., Mikkelsen, C. A., & Aslin, R. N. (2025). Neural hyperscanning in caregiver-child dyads: A paradigm for studying the long-term effects of facilitated vs. disrupted attention on working memory and executive functioning in young children. *Developmental Review, 75*, 101170. https://doi.org/10.1016/j.dr.2024.101170

Ruffini, C., Chini, C., Lombardi, G., Della Rocca, S., Monaco, A., Campana, S., & Pecini, C. (2024). Training executive functions within the mathematical domain: A pilot study with an integrated digital-paper procedure in primary second-grade. *Mind, Brain, and Education, 18*(1), 85–102. https://doi.org/10.1111/mbe.12404

Sambol, S., Suleyman, E., Scarfo, J., & Ball, M. (2023). A true reflection of executive functioning or a representation of task-specific variance? Re-evaluating the unity/diversity framework. *Acta Psychologica, 236*. https://doi.org/10.1016/j.actpsy.2023.103934

Saricaoglu, M., Yücel, M. A., Budak, M., Omurtag, A., & Hanoglu, L. (2025). Different cortex activation between young and middle-aged people during different type problem-solving: An EEG & fNIRS study. *NeuroImage, 308*. https://doi.org/10.1016/j.neuroimage.2025.121062

Schoenel, A. S. P., Escarce, A. G., Araújo, L. L., & Lemos, S. M. A.. (2020). Influência do processamento fonológico no mau desempenho escolar: revisão sistemática de literatura. *Codas*, *32*(5), e20180255. https://doi.org/10.1590/2317-1782/20192018255

Schwarze, S. A., Laube, C., Khosravani, N., Lindenberger, U., Bunge, S. A., & Fandakova, Y. (2023). Intensive task-switching training and single-task training differentially affect behavioral and neural manifestations of cognitive control in children. *bioRxiv*. https://doi.org/10.1101/2023.12.22.573065

Shende, S. A., & Mudar, R. A. (2023). Cognitive control in age-related hearing loss: A narrative review. *Hearing Research*, *436*, 108814. https://doi.org/10.1016/j.heares.2023.108814

Simão, G. F., Corrêa, T. H. B., & Ferrandini, L. M. (2020). Contribuições da Neuropsicopedagogia no Contexto Educacional: um novo olhar para a instituição escolar. *Educere Et Educare*, *15*(36). https://doi.org/10.17648/educare.v15i36.25115

Singh, S., Sandhu, K. & Lokesh (2024). Effect of Cognitive Training on Processing Speed of School Going Children: An Intervention Study with 3X3 Rubik Cube. *International Journal of Indian Psychology*, *12*(3), 1157-1164. DIP:18.01.112.20241203, DOI:10.25215/1203.112

Siqueira, C. M., & Gurgel-Giannetti, J. (2011). Mau desempenho escolar: uma visão atual. *Revista Da Associação Médica Brasileira*, *57* (1), 78–87. https://doi.org/10.1590/S0104-42302011000100021

Souto, D., & Kerzel, D. (2021). Visual selective attention and the control of tracking eye movements: a critical review. *Journal of Neurophysiology*, *125*(5), 1552–1576. https://doi.org/10.1152/jn.00145.2019

Souza, J. B., Trevisan, B. T., Nunes, L. G., Machado, W. L., & Seabra, A. G. (2024). A Naturalistic Intervention to Promote Executive Functions in Primary School Children: A Pilot Study. *Brain Sciences*, *14*(1), 70. https://doi.org/10.3390/brainsci14010070

Sridhar, S., Khamaj, A., & Asthana, M. K. (2023). Cognitive neuroscience perspective on memory: Overview and summary. *Frontiers in Human Neuroscience, 17*. https://doi.org/10.3389/fnhum.2023.1217093

Tan, E., Troller-Renfree, S. V., Morales, S., Buzzell, G. A., McSweeney, M., Antúnez, M., & Fox, N. A. (2024). Theta activity and cognitive functioning: Integrating evidence from resting-state and task-related developmental electroencephalography (EEG) research. *Developmental Cognitive Neuroscience*, *67*. https://doi.org/10.1016/j.dcn.2024.101404

Thornhill-Miller B, Camarda A, Mercier M, Burkhardt J-M, Morisseau T, Bourgeois-Bougrine S, Vinchon F, El Hayek S, Augereau-Landais M, Mourey F, *et al.* Creativity, Critical Thinking, Communication, and Collaboration: Assessment, Certification, and Promotion of 21st Century Skills for the Future of Work and Education. *Journal of Intelligence*. 2023; 11(3):54. https://doi.org/10.3390/jintelligence11030054

Tian, H., Wang, Z., Meng, Y., Geng, L., Lian, H., Shi, Z., Zhuang, Z., Cai, W., & He, M. (2025). Neural mechanisms underlying cognitive impairment in depression and cognitive benefits of exercise intervention. *Behavioural Brain Research, 476*. https://doi.org/10.1016/j.bbr.2024.115218

Träff, U., Östergren, R., Skagerlund, K., & Skagenholt, M. (2025). Mental arithmetic skill development in primary school: The importance of number processing abilities and general cognitive abilities. *Journal of Experimental Child Psychology, 252*. https://doi.org/10.1016/j.jecp.2024.106155

Trammell, J. P., MacRae, P. G., Davis, G., Bergstedt, D., & Anderson, A. E. (2017). The relationship of cognitive performance and the theta-alpha power ratio is age-dependent: An EEG study of short-term memory and reasoning during task and resting-state in healthy young and old adults. *Frontiers in Aging Neuroscience, 9*, 364. https://doi.org/10.3389/fnagi.2017.00364

van Balkom, T. D., van den Heuvel, O. A., Berendse, H. W., & others. (2020). The effects of cognitive training on brain network activity and connectivity in aging and neurodegenerative diseases: A systematic review. *Neuropsychology Review, 30*, 267–286. https://doi.org/10.1007/s11065-020-09440-w

Vidaurre, D. (2024). A generative model of electrophysiological brain responses to stimulation. *eLife, 12*. https://doi.org/10.7554/eLife.87729.3

Vita-Barrull, N., Estrada-Plana, V., March-Llanes, J., Guzmán, N., Fernández-Muñoz, C., Ayesa, R., & Moya-Higueras, J. (2023). Board game-based intervention to improve executive functions and academic skills in rural schools: A randomized controlled trial. *Trends in Neuroscience and Education, 33*. https://doi.org/10.1016/j.tine.2023.100216

Viviani, G., & Vallesi, A. (2021). EEG-neurofeedback and executive function enhancement in healthy adults: A systematic review. *Psychophysiology*, *58*(9). https://doi.org/10.1111/psyp.13874

Yu, J., Abdullah, M. F. I. L., & Mansor, N. S. (2024). EEG components of inhibitory control ability in internet gaming disorder: A systematic review and meta-analysis of randomized controlled trials. *Brain and Behavior*, 14. https://doi.org/10.1002/brb3.3388

Wang, W., Li, H., Wang, Y., Liu, L., & Qian, Q. (2024). Changes in effective connectivity during visual-motor integration tasks: A preliminary f-NIRS study. *Behavioral and Brain Functions, 20*, 4. https://doi.org/10.1186/s12993-024-002323

Wang, M., & Lyu, B. (2024). Effect of 24-form simplified Tai Chi on executive inhibitory control of college students: A randomized controlled trial of EEG. *Frontiers in Psychology, 15*. https://doi.org/10.3389/fpsyg.2024.1344989

Wei, H., Chen, L., & Zhao, L. (2024). Can the Spontaneous Electroencephalography Theta/Beta Power Ratio and Alpha Oscillation Measure Individuals' Attentional Control? *Behavioral Sciences*, *14*(3), 227. https://doi.org/10.3390/bs14030227

Whybird, M., Coats, R., Vuister, T., Harrison, S., Booth, S., & Burke, M. (2021). The role of the posterior parietal cortex on cognition: An exploratory study. *Brain Research, 1764*, 147452. https://doi.org/10.1016/j.brainres.2021.147452

Wu, Q., Wu, C., & Liu, J. (2024). Research progress on the intervention of cognitive function using transcranial alternating current stimulation technology. *Frontiers in Psychology*, *15*. https://doi.org/10.3389/fpsyg.2024.1405636

Zhang, Y., Tolmie, A., & Gordon, R. (2022). The Relationship between Working Memory and Arithmetic in Primary School Children: A Meta-Analysis. *Brain sciences*, *13*(1), 22. https://doi.org/10.3390/brainsci13010022

Zühlsdorff, K., Dalley, J. W., Robbins, T. W., & Morein-Zamir, S. (2023). Cognitive flexibility: neurobehavioral correlates of changing one's mind. *Cerebral cortex (New York, N.Y.: 1991)*, *33*(9), 5436–5446. https://doi.org/10.1093/cercor/bhac431