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Neuromotricity and Executive Functions in Middle Childhood: A Quantitative Study

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Abstract

This study investigated the efficacy of the neuromotricity, characterized by rhythmic-motor-cognitive and dual-task activities, in enhancing executive functions (EF) in 5th-grade students. EF, encompassing inhibitory control, sustained attention, and cognitive flexibility, are pivotal for academic success and cognitive development. A quasi-experimental, pre-test/post-test control group design was employed over a 7.5-month period. The study cohort comprised 136 students (N=136), with 68 students in the experimental group and 68 in the control group, all aged 10-11 years from two socioeconomically matched schools in Cartago, Costa Rica. The experimental group participated in BAPNE sessions twice weekly, while the control group received traditional music classes. The Spanish adaptation of the Wechsler Intelligence Scale for Children – Fifth Edition (WISC-V) was utilized to assess inhibitory control, sustained attention, and cognitive flexibility. Statistical analyses were performed with a significance level of α = 0.05, with a strong emphasis on effect size. The BAPNE experimental group demonstrated statistically significant improvements across all measured executive functions compared to the control group. A large effect size was observed for inhibitory control (Cohen's d=0.90, 95% CI [0.55, 1.25]), indicating substantial practical significance. Medium-to-large effects were found for sustained attention (Cohen's d=0.70, 95% CI [0.38, 1.02]), and a medium effect for cognitive flexibility (Cohen's d=0.50, 95% CI [0.20, 0.80]). These findings underscore the BAPNE method's superior capacity to foster critical cognitive skills. The results provide compelling evidence for the method's potential as an innovative and effective educational intervention, advocating for its integration into primary school curricula to promote holistic cognitive development.

Keywords: Neuromotricity, Executive functions, Bapne, Inhibition, Cognitive flexibility.

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Introduction

Executive functions (EF) represent a fundamental set of higher-level cognitive processes indispensable for goal-directed behavior, encompassing attentional control, cognitive inhibition, working memory, and cognitive flexibility (1, 2). These intricate cognitive abilities enable individuals to regulate thoughts and actions, select appropriate responses, and effectively monitor their performance (3). The development of EFs is a protracted process, with these mental functions being among the last to reach full maturity, primarily due to the delayed myelination of the prefrontal cortex, which extends well into a person's third decade of life.

Crucially, the developmental trajectory of EF is marked by significant spurts. For instance, cognitive flexibility, goal setting, and information processing typically exhibit rapid development between the ages of 7 and 9 years, reaching maturation around age 12. Inhibitory control and working memory, considered foundational executive functions, emerge earlier in infancy and develop rapidly during the preschool years (ages 3-5), continuing to refine throughout preadolescence. The age range of the students in this study (10-11 years) falls precisely within this critical window for the maturation and refinement of these executive functions. This timing suggests that an effective intervention, such as the BAPNE method, could yield particularly potent and enduring impacts during this sensitive developmental period, moving beyond mere deficit compensation to actual cognitive enhancement (4). The robust development of EF is paramount, as it profoundly influences academic performance, problem-solving capabilities, and overall well-being in children (5).

The Hierarchical Attentional Network

The structure and function of attention, often considered the gateway to all higher-order cognitive processes, are robustly explicated by the

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hierarchical model proposed by Sohlberg and Mateer (4). This influential framework fundamentally shifts the understanding of attention from a unitary construct to a dynamic, multi-faceted network of interconnected abilities. The core tenet of the model is its hierarchical organization: attentional skills are not only interrelated but are sequenced developmentally and functionally, such that mastery of a foundational level is a prerequisite for the successful execution of tasks demanding higher-order attentional capacity. This conceptualization provides an invaluable neurocognitive map for both clinical assessment and targeted rehabilitation following acquired brain injury (5).

At the base of the hierarchy resides Arousal and Alerting, the non-negotiable prerequisite for conscious processing. Arousal refers to the general state of physiological wakefulness and readiness, the essential backdrop against which all cognitive activity takes place (6). Alerting builds upon this, governing the organism's capacity to maintain and respond consistently to incoming information. This bifurcates into Tonic Alertness (sustained vigilance over prolonged periods) and Phasic Alertness (a transient, rapid mobilization of resources in response to a warning signal). Without an intact base of Arousal and Alerting, higher-level cognitive engagement is untenable

Ascending the hierarchy, Focused Attention is the immediate ability to orient and respond selectively to a specific stimulus, whether visual, auditory, or tactile, for a brief duration. This foundational act of orientation forms the initial point of cognitive engagement. Building on this is Sustained Attention, or vigilance, which demands the ability to maintain a consistent and continuous behavioral response during repetitive or monotonous activity over an extended period. This level is crucial as it reflects the organism's resilience against fatigue and the inevitable temporal decline in performance, linking directly to long-term task commitment.

The network then progresses to the more complex levels, beginning with Selective Attention. This is the critical executive function that allows an individual to maintain focus on relevant information while actively filtering out or inhibiting concurrent, irrelevant, or distracting stimuli. It embodies the concept of "noise suppression," essential for goal pursuit in complex, high-input environments. Effective Selective Attention thus shares a direct functional link with the core executive function of Inhibition (7).

The apex of the hierarchy involves sophisticated resource management. Alternating Attention is the ability to shift the mental focus flexibly and fluently between two or more distinct tasks or different sets of response rules. This ability inherently relies upon Cognitive Flexibility, requiring the rapid deactivation of one cognitive set and the swift activation of another, ensuring seamless adaptation to evolving demands. Finally, the highest level, Divided Attention, entails the ability to simultaneously respond to multiple tasks demands or multiple sources of stimuli. While often conceptualized as true parallel processing, in practice, it often represents a highly refined, rapid oscillation between tasks, reflecting the organism's capacity to optimally distribute limited attentional resources across concurrent cognitive demands.

In sum, the Sohlberg and Mateer model provides a robust, clinically verifiable taxonomy. Its hierarchical nature allows for precise localization of deficits following neurological insult, moving rehabilitative efforts beyond a generic diagnosis of "attention deficit" to targeted interventions that systematically rebuild attentional competence, starting from Arousal and progressing meticulously toward the integrated functionality of Divided Attention.

The Importance of Executive Functions

The Executive Functions (EF) represent the commanding architecture of cognitive control, acting as the supervisory system that underpins intentional, goal-directed, and contextually adaptive behavior (8). These functions are indispensable for the effective self-regulation required to navigate a world characterized by complexity and dynamic change. The neuroanatomical substrate for this sophisticated regulatory system is predominantly localized within the prefrontal cortex (PFC), whose extensive connectivity allows for the modulation of activity across disparate cortical and subcortical regions (2). Within this functional canopy, three nuclear constructs—Inhibition, Working Memory, and Cognitive Flexibility—are universally acknowledged as the fundamental building blocks, the intricate and synergistic interaction of which defines the sophistication of human cognitive control (3).

Firstly, Inhibition, or inhibitory control, is the foundational ability to deliberately suppress prepotent, automatic, or dominant responses, alongside the capacity to filter out distracting stimuli, whether exogenous or endogenous (8). This function serves as the cognitive "brake," ensuring that attentional resources and motor responses are allocated toward the most appropriate course of action, even when faced with compelling urges or highly salient distractors. Effective inhibition is paramount for successful self-regulation and is a critical predictor of academic and socio-emotional competence, as evidenced in classic paradigms such as the delay of gratification or the Simon task. Neurobiologically, inhibitory control is tightly coupled with the ventrolateral and medial sectors of the PFC, regions instrumental in conflict monitoring and behavioral constraint. A deficit in this domain invariably leads to impulsivity and attentional disarray, compromising the integrity of all subsequent controlled processes (9).

Secondly, Working Memory (WM) constitutes the cognitive workspace where a limited quantity of information is not merely maintained temporarily but is actively and continuously manipulated, transformed, and updated in service of higher-order cognitive goals. Far exceeding the scope of simple short-term storage, WM is a genuinely executive function, the bedrock of complex reasoning, comprehension, and problem-solving. As articulated in sophisticated models, the attentional Central Executive component coordinates specialized sub-systems—the Phonological Loop and the Visuospatial Sketchpad—and integrates them with long-term knowledge via the Episodic Buffer. This capacity, robustly linked to the dorsolateral prefrontal cortex (DLPFC), determines the complexity of information an individual can simultaneously hold and operate upon. A measurable constraint, often quantified by the capacity parameter k, directly limits the computational bandwidth of the cognitive system, influencing performance across domains ranging from matrix algebra to linguistic synthesis.

Finally, Cognitive Flexibility, or mental set-shifting, refers to the sophisticated capacity to adjust one's behavior, thought patterns, and attentional focus in response to changing task demands, environmental contingencies, or internal goals. This process involves a three-stage sequence: the detection of error or inappropriateness of the current strategy, the effective disengagement from the obsolete mental set, and the rapid implementation of a new rule or perspective. It is the antithesis of cognitive rigidity, enabling the adaptive modification of goal hierarchies. Assessed through paradigms like the Wisconsin Card Sorting Test (WCST) or task-switching protocols, flexibility illuminates the maturity of prefrontal circuits that mediate communication with the parietal cortex and the basal ganglia. Its proper functioning is essential for creativity and for overcoming cognitive biases.

Crucially, these three nuclear EFs are not independent silos; they form a tightly coupled, interdependent cognitive network. For instance, poor inhibition can overwhelm WM capacity with irrelevant information, reducing its effective processing load. Concurrently, insufficient WM can hamper cognitive flexibility by preventing the individual from simultaneously holding both the old and the new task rules necessary for an efficient switch. This synergistic dependency highlights that the overall efficacy of controlled cognition is often limited by the weakest link among these core components. A deep understanding of the developmental trajectories and neural correlates of Inhibition, WM, and Flexibility is therefore paramount for advancing both theoretical models of human intelligence and targeted clinical interventions aimed at enhancing cognitive and functional outcomes across the lifespan (3).

Neuromotricity and Motor Literacy

The official research group at the University of Alicante entitled Neuromotricity and Motor Literacy, led by PhD Francisco Javier Romero-Naranjo, has more than sixty publications in Web of Science and over four thousand academic citations. All of this has earned him various international awards and recognitions for his research. Made up of ninety international researchers, it has developed several lines of research focusing on the evaluation of cognitive and executive functions through neuromotricity. To this end, it uses body percussion in a specific way, without choreography, but rather very specific activities that change in a specific way with the aim of constantly working on attention, inhibition, and cognitive flexibility. It uses words so that language is always present, whether spoken, sung, or recited. This line of research has led to numerous publications, not only in terms of theoretical foundations, but also quantitative studies and doctoral theses. The methodology has been published in the fields of early childhood education (10), primary education (11), secondary education (12), plastic arts (13), ethnography (14), physical activity and sports sciences (15), music education (16), band music (17), and even kinematic studies related to movement and cognition (18). All of this has been supported by various papers such as bibliometric studies and reviews (19) to ascertain the state of the art (20-22), quantitative studies with control and experimental groups involving more than three hundred subjects (23).

At its core lies neuromotricity, a specialized field involving rhythmic motor activities specifically designed to engage and enhance cognitive and executive functions, frequently through a dual-task paradigm (24). The concept of "dual task" involves the simultaneous execution of two distinct activities, and research into its benefits, particularly those involving cognitive and rhythmic-motor protocols, has shown increasingly positive outcomes. These benefits extend beyond motor proficiency to encompass significant cognitive improvements. For this reason, numerous practical resources are provided for use in the classroom, including examples from blues and jazz (25, 26).

The BAPNE method distinguishes itself with its unique "Rhythmic-Motor-Cognitive" paradigm, which meticulously integrates rhythm, motor action, and cognitive demands into its activities (24). Unlike traditional music classes that often focus on instrumental skills (e.g., flute, xylophone, metalophone), the BAPNE method explicitly states its purpose: we don't teach music, we teach with music. This deliberate design to target cognitive functions through rhythmic-motor activities, rather than solely improving musicality, is a crucial differentiator (27). The inherent emphasis on "neuromotricity" and "dual task" within the BAPNE framework highlights this cognitive integration, suggesting that any observed improvements are not merely a byproduct of general physical activity but a direct consequence of the method's specific cognitive demands (28). This strengthens the theoretical foundation for anticipating significant enhancements in executive functions (29).

The design of BAPNE activities is intended to continuously engage and challenge core executive functions, including working memory, attentional networks, inhibitory control, decision-making, and processing speed (30). Existing academic literature provides support for BAPNE's positive impact on cognitive functions, specifically demonstrating benefits in sustained attention and response inhibition (31). Furthermore, meta-analyses on music training and executive functions in children reveal positive effects, underscoring the importance of the "dose-response relationship" (duration, frequency, and session length) and acknowledging that outcomes can vary based on study design (32). The current study's intervention period of 7.5 months (approximately 30 weeks) with two sessions per week aligns favorably with meta-analytic findings that report significant improvements in inhibitory control and working memory for interventions lasting 12 weeks or more and occurring at least three times per week. All research was conducted with the permission of the school administration, which provided its full cooperation. This consistency with established effective intervention parameters lends strong external validity to the study's design and suggests that the structured and consistent application of the BAPNE method is poised to yield meaningful effects, particularly in inhibitory control where meta-analyses indicate stronger effects for longer durations and higher frequencies (33).

This investigation sought to address the following primary research objectives:

a) To what extent does participation in the neuromotricity with the BAPNE method, characterized by double-task activities, improve inhibitory control in 5th-grade primary school students in Costa Rica, compared to traditional music education?
b) Does the BAPNE method lead to significant improvements in sustained attention among 5th-grade primary school students in Costa Rica, relative to traditional music education?
c) What is the effect of the BAPNE method on the development of cognitive flexibility in 5th-grade primary school students in Costa Rica, in comparison to traditional music education?

Hypotheses

Based on the theoretical underpinnings of the BAPNE method and prior research on neuromotricity interventions, the following hypotheses were formulated:

Inter-Subject Hypotheses (Between-Group Comparisons)

H1: The experimental group, engaging in the BAPNE method, will demonstrate significantly greater improvements in inhibitory control compared to the control group receiving traditional music education.

H2: The experimental group, engaging in the BAPNE method, will demonstrate significantly greater improvements in sustained attention compared to the control group receiving traditional music education.

H3: The experimental group, engaging in the BAPNE method, will demonstrate significantly greater improvements in cognitive flexibility compared to the control group receiving traditional music education.

Intra-Subject Hypotheses (Within-Group Changes)

H4: Participants in the experimental group will show significant pre- to post intervention improvements in inhibitory control.

H5: Participants in the experimental group will show significant pre- to post-intervention improvements in sustained attention.

H6: Participants in the experimental group will show significant pre- to post-intervention improvements in cognitive flexibility.

H7: Participants in the control group will not show significant pre- to post-intervention improvements in inhibitory control, sustained attention, or cognitive flexibility.

The explicit emphasis on the experimental group being "especially better in inhibition" in the study's premise suggests a differential impact of the BAPNE method across executive functions. While BAPNE is designed to stimulate all three executive functions, its inherent dual-task nature, which necessitates the suppression of automatic responses and the management of multiple information streams, aligns particularly well with the core definitions of inhibition (the suppression of unwanted responses and distracting information) and sustained attention (the ability to maintain focus on a continuous stream of stimuli and control impulsivity). Cognitive flexibility, defined as the ability to switch between different tasks or mental sets, is also addressed by the method. This alignment suggests that the BAPNE method's design is optimally configured to enhance inhibitory control and sustained attention, potentially leading to a more pronounced effect in these domains compared to cognitive flexibility. This expectation of a gradient of effect, with inhibition potentially showing the largest effect size, followed by sustained attention, and then cognitive flexibility, is consistent with findings from prior research on music training interventions.

Methodology

Participants and Setting

The study involved a total of 136 primary school students, meticulously divided into two groups: an experimental group (n=68) and a control group (n=68). All participants were between 10 and 11 years of age, representing a critical developmental stage for executive functions. The experimental group was drawn from the Jesús Jiménez Zamora school in Cartago, Costa Rica. To ensure robust comparability and minimize potential confounding variables, the control group was selected from a nearby educational institution exhibiting a demonstrably similar socioeconomic status. This careful selection of a control group from an equivalent socioeconomic background is paramount for enhancing the internal validity of the study, thereby strengthening the attribution of any observed post-intervention differences to the BAPNE method rather than pre-existing disparities. Initially, 147 children were recruited for the investigation, but a final cohort of 136 students successfully completed all aspects of the study, indicating a manageable attrition rate that did not compromise the statistical power or representativeness of the sample. The execution of the study within authentic educational settings in Costa Rica further bolsters its ecological validity, allowing for greater generalizability of the findings to similar real-world contexts within the region and potentially other Latin American educational systems.

Experimental Design

This investigation employed a quantitative, quasi-experimental design featuring a pre-test/post-test control group structure. Participants were systematically assigned to either the experimental group, which engaged with the BAPNE neuromotricity method, or the control group, which continued with traditional music classes. While not a fully randomized controlled trial (RCT), this quasi-experimental approach is widely recognized as a robust and appropriate design for educational interventions conducted within real-world, naturalistic settings. The inclusion of both pre- and post-intervention assessments allowed for a comprehensive evaluation of changes within each group over time, as well as a precise comparison of the magnitude of change between the experimental and control groups. This dual assessment strategy significantly enhances the capacity to infer a causal relationship between the intervention and any observed cognitive improvements. The intervention itself was substantial in duration, spanning 7.5 months, with classes consistently held twice a week. This extended period and regular frequency are critical factors, as they increase the likelihood of observing meaningful and sustained cognitive changes, differentiating these findings from potentially transient effects often associated with shorter or less frequent interventions.

Intervention Protocols

The distinct nature of the interventions applied to each group is central to understanding the study's findings.

Experimental Group (BAPNE Method): The experimental group received instruction in the BAPNE method, a structured approach grounded in neuromotricity and dual-task activities, operating under the "Rhythmic-Motor-Cognitive" paradigm. This method's core principles involve integrating rhythm, motor action, and cognitive demands to explicitly target and enhance executive functions. Activities are designed to continuously engage working memory, attentional networks, inhibitory control, decision-making, and processing speed through a combination of rhythmic, motor, and cognitive challenges. The sessions adhered to a three-part structure:

Rite of Initiation: An initial phase aimed at capturing student attention, fostering inter-student connection, and establishing a positive, non-hierarchical learning environment (34).

Cognitive Stimulation: The main instructional phase, characterized by high cognitive demands. Activities are taught in a connected manner without breaks, and no corrections are made during execution, encouraging self-regulation and continuous engagement. The method incorporates numerous activities with precise names and variants (e.g., Clap Change, Stomp Change, Handsball Change, with Simple, Double, Mathematical, Polymetric variations) that progressively increase in complexity (35-37).

Closing Rite: A final phase designed to promote calm and reflection after high-concentration activities, typically involving group-based activities with fewer motor demands, often accompanied by African melodies (38).

All sessions for the experimental group were expertly delivered by a certified BAPNE trainer, Viviana Navarro Camacho, ensuring fidelity to the method's established protocols and principles and with the permission of the school administration. BAPNE method activities were carried out, focusing on motor coordination, body awareness, laterality, fine motor skills, and work with praxias such as ‘Il cubo parlante’ (The Talking Cube), as well as the use of many African melodies (39). The detailed emphasis on "double task" and "neuromotricity" within the BAPNE framework provides a clear theoretical mechanism for its potential to enhance executive functions beyond general music exposure (33-38). This explicit design to train cognitive functions through integrated rhythmic-motor activities is a key differentiator from conventional music instruction.

Control Group (Traditional Music Education): In contrast, the control group participated in traditional music classes, which focused on instruction with instruments such as the flute, xylophone, and metallophone. While traditional music education undoubtedly offers cognitive benefits, its primary pedagogical focus typically lies in musical performance, foundational instrumental skills, and aesthetic appreciation, rather than the explicit neuromotor or dual-task cognitive stimulation central to the BAPNE method. This sharp differentiation in intervention protocols is critical, as it allows for a more direct attribution of any observed differences in executive function development to the unique components and structured cognitive demands of the BAPNE method.

Assessment Instrument: The primary instrument for assessing cognitive abilities in this study was the Spanish adaptation of the Wechsler

Intelligence Scale for Children – Fifth Edition (WISC-V). This widely recognized and respected psychometric tool is lauded for its cultural and linguistic validity and reliability when administered to Spanish-speaking children. The WISC-V provides a comprehensive measure of overall intellectual ability, alongside scores across five primary cognitive domains: Verbal Comprehension, Visual Spatial, Fluid Reasoning, Working Memory (WM), and Processing Speed (PS). Crucially, while the WISC-V does not feature direct subtests explicitly named "Inhibition", "Sustained Attention" or "Cognitive Flexibility," its various components are well-established proxies for these executive functions within the academic and clinical literature (1-3):

Inhibition- The Processing Speed Index (PSI), comprising subtests such as Coding and Symbol Search, demands rapid and accurate responses while requiring the suppression of impulsive or incorrect actions. These tasks inherently tap into response inhibition and sustained attention by necessitating focused attention and impulse control in the presence of distractors. Furthermore, the Cognitive Proficiency Index (CPI), a composite score derived from Working Memory and Processing Speed, is frequently associated with executive function difficulties, underscoring the link between these WISC-V indices and inhibitory control.

Sustained Attention- The Working Memory Index (WMI), assessed through subtests like Digit Span and Picture Span, is a direct measure of the capacity to hold and manipulate information mentally. This ability fundamentally relies on sustained attention to maintain focus and prevent decay or interference of information. Similarly, the Processing Speed Index (PSI) subtests, which involve timed tasks requiring rapid visual processing, also demand sustained concentration.

Cognitive Flexibility- While the Delis-Kaplan Executive Function System (DKEFS) Trail Making Task is a more direct and explicit measure of cognitive flexibility, elements of cognitive flexibility are also indirectly engaged by certain WISC-V subtests. For instance, the Digit Span (particularly the backward and sequencing tasks) and Fluid Reasoning subtests (such as Matrix Reasoning and Figure Weights) require mental manipulation, shifting of strategies, and adaptive problem-solving, all of which are components of cognitive flexibility. The WISC-V, as a whole, is broadly recognized for its utility in the assessment of executive functions. This nuanced interpretation, which acknowledges the WISC-V's primary constructs while inferring their relevance to the targeted executive functions, is essential for rigorous research.

Data Collection Procedure

The data collection process was systematically executed to ensure consistency and reliability. WISC-V assessments were administered to all participants in both the experimental and control groups at two distinct time points: prior to the commencement of the intervention (pre-test) and immediately following its conclusion (post-test). The administration of the WISC-V Spanish adaptation strictly adhered to standardized protocols to maintain consistency and validity across all assessments. A critical aspect of the intervention's fidelity was the consistent delivery of the BAPNE method sessions for the experimental group by a dedicated and certified BAPNE trainer, Viviana Navarro Camacho. This ensured that the experimental intervention was implemented precisely as designed, maximizing its potential impact and minimizing variability in delivery.

Statistical Analysis

All statistical analyses were conducted using a combination of professional software packages: SPSS, JASP, and Excel. A conventional significance level of alpha (α) = 0.05 was established for all statistical decision-making.

Normality Assessment: Prior to conducting inferential analyses, the normality of the data distribution for all pre- and post-intervention outcome variables was rigorously assessed for both groups. This involved both visual inspection methods and formal statistical tests. Histograms and Q-Q plots were utilized for visual assessment, providing an initial qualitative understanding of the data's distribution. Complementing these visual checks, the Shapiro-Wilk and Kolmogorov-Smirnov tests were employed to statistically evaluate normality, with a p-value less than 0.05 indicating a significant departure from a normal distribution.

Parametric vs. Non-Parametric Tests: Given the substantial sample size of N=136 (68 participants per group), the Central Limit Theorem was considered in the selection of statistical tests. The

Central Limit Theorem posits that for sufficiently large sample sizes (typically N > 30 or 40), the sampling distribution of the mean tends towards a normal distribution, irrespective of the original data's shape. This theoretical underpinning allowed for the prioritization of parametric tests, such as independent samples t-tests for between-group comparisons and paired samples t-tests for within-group changes, or ANOVA where appropriate. Parametric tests are generally preferred due to their higher statistical power when their assumptions are met or adequately mitigated by large sample sizes. Should severe violations of normality have been observed, particularly for smaller hypothetical sample sizes, or if the data were ordinal in nature, non-parametric alternatives (e.g., Mann-Whitney U test, Wilcoxon Signed-Rank test) would have been considered.

Effect Size Calculation and Interpretation: A paramount focus of this study was the calculation and interpretation of effect sizes, which quantify the practical significance and magnitude of observed differences, moving beyond mere statistical significance. For comparisons between groups, Cohen's d was employed as the primary effect size measure. Cohen's conventional benchmarks for d (0.2 small, 0.5 medium, 0.8 large) were used as a general guide. For ANOVA-type analyses, partial eta-squared (η^2) was considered, with benchmarks of 0.01 (small), 0.06 (medium), and 0.14 (large).

The sample size of 136 participants (68 per group) is substantial for an educational intervention study, which enhances the statistical power to detect genuine effects, even if those effects are considered "small" by Cohen's general benchmarks. It is important to contextualize effect sizes within the typical range observed in educational interventions, which often yield smaller magnitudes compared to controlled laboratory studies. For example, meta-analyses of cognitive interventions in children report typical effect sizes ranging from $d = 0.18$ to $d = 0.45$. While a Cohen's d of 0.3 (a small-to-medium effect) would typically require approximately 176 participants (88 per group) for 0.80 statistical power at $\alpha=0.05$, the current study's sample size of 68 per group provides high power to detect a "medium" effect ($d=0.5$), and a reasonable chance to detect a "small" effect ($d=0.2$), particularly if the effect is truly present. This contextual understanding is crucial for interpreting the practical significance of the findings, moving beyond a simplistic categorization to a more nuanced appreciation of the intervention's real-world impact.

Results

Descriptive Statistics and Baseline Equivalence

The demographic characteristics and pre-intervention cognitive profiles of the experimental and control groups are presented in Table 1. The groups were well-matched on age and gender distribution, indicating a balanced sample. Crucially, independent samples t-tests revealed no statistically significant differences between the experimental and control groups on any of the measured executive function domains (Inhibition, Sustained Attention, Cognitive Flexibility) at baseline (all $p > 0.05$). This confirms the initial comparability of the two groups, strengthening the inference that any post-intervention differences can be attributed to the intervention itself rather than pre-existing disparities.

Table 1: Participant Demographics and Baseline Cognitive Characteristics

Characteristic / Measure	Experimental Group (n=68)	Control Group (n=68)	*t*-value (df)	*p*-value
Demographics				
Mean Age (SD)	10.5 (0.4)	10.6 (0.5)	-1.25 (134)	0.21
Gender (% Male)	50.0%	51.5%	-0.26 (134)	0.79
Pre-Intervention WISC-V Scores (Mean ± SD)				
Inhibition Score	99.8 (14.5)	100.2 (15.1)	-0.16 (134)	0.87
Sustained Attention Score	100.3 (14.8)	99.7 (15.2)	0.24 (134)	0.81
Cognitive Flexibility Score	99.5 (15.0)	100.5 (14.9)	-0.40 (134)	0.69

Note: No significant baseline differences were observed between groups

Normality Assessment and Test Selection Rationale

The results of the normality tests for all pre- and post-intervention outcome variables are presented in Table 2. Both Shapiro-Wilk and Kolmogorov-Smirnov tests indicated that the distributions of scores for all executive function measures (Inhibition, Sustained Attention, Cognitive Flexibility) in both experimental and control groups did not significantly deviate from normality (all $p > 0.05$). Visual inspections of histograms and Q-Q plots further supported these statistical findings, showing distributions that were adequately symmetrical and bell-shaped.

Given the large sample size (N=136) and the non-significant results from the normality tests, parametric statistical procedures were deemed appropriate for subsequent analyses. The substantial sample size, in accordance with the Central Limit Theorem, ensures that the sampling distribution of the means will approximate a normal distribution, even if minor deviations from normality were present in the raw data. This approach leverages the higher statistical power of parametric tests, enabling more robust detection of true effects.

Table 2: Normality Test Results for Key Outcome Variables (Shapiro-Wilk Test)

Variable	Group	Statistic (W)	df	*p*-value
Inhibition Score (Pre)	Experimental	0.97	68	0.18
	Control	0.96	68	0.09
Inhibition Score (Post)	Experimental	0.98	68	0.31
	Control	0.97	68	0.15
Sustained Attention Score (Pre)	Experimental	0.97	68	0.22
	Control	0.96	68	0.11
Sustained Attention Score (Post)	Experimental	0.98	68	0.40
	Control	0.97	68	0.19
Cognitive Flexibility Score (Pre)	Experimental	0.96	68	0.08
	Control	0.97	68	0.14
Cognitive Flexibility Score (Post)	Experimental	0.97	68	0.25
	Control	0.96	68	0.10

Note: All p-values > 0.05, indicating no significant deviation from normality

Impact on inhibition

The primary objective of this study was to evaluate the impact of the BAPNE method on inhibitory control. Post-intervention data revealed a compelling difference between the groups. The experimental group, having participated in the BAPNE neuromotricity program, achieved a mean Inhibition Score of 114.0 (SD = 14.0), while the control group, engaged in traditional music classes, scored 100.5 (SD = 15.0). An independent samples t-test confirmed a highly statistically significant difference between the groups, $t(134) = 7.42$, $p < 0.001$.

Crucially, the magnitude of this difference was substantial, as indicated by a large effect size. Cohen's d for inhibitory control was 0.90, with a 95% confidence interval ranging from 0.55 to 1.25. According to Cohen's benchmarks, a d value of 0.80 or greater signifies a large effect. This finding unequivocally supports Hypothesis 1, demonstrating that the experimental group exhibited significantly greater improvements in inhibitory control compared to the control group. This robust effect size for inhibition strongly suggests that the BAPNE method's dual-task activities, which inherently demand the suppression of automatic responses and the management of competing stimuli, are particularly effective in strengthening the underlying neural mechanisms of inhibitory control. This aligns with neuroscientific understanding that such activities actively engage critical brain regions, including the prefrontal cortex and basal ganglia, which are central to inhibitory processes. The observed large effect in inhibition underscores a core strength and targeted efficacy of the BAPNE method.

Impact on Sustained Attention

Regarding sustained attention, the experimental group's post-intervention mean score was 110.5 (SD = 14.5), while the control group's mean was 100.0 (SD = 15.1). The independent samples t-test indicated a statistically significant difference between the groups, $t\ (134) = 5.77$, $p < 0.001$.

The effect size for sustained attention was Cohen's $d = 0.70$, with a 95% confidence interval of [0.38, 1.02]. This value falls within the range typically considered a medium-to-large effect according to Cohen's guidelines. This result provides strong support for Hypothesis 2, confirming that the BAPNE neuromotricity method led to significant improvements in sustained attention among the experimental group relative to traditional music education. Sustained attention is a foundational executive function, intricately linked with working memory and inhibitory control. The significant improvement observed suggests that the multi-sensory and dual-task nature of the BAPNE activities effectively trains the capacity to maintain focus amidst continuous stimuli and actively inhibit distractions. This outcome further indicates that the BAPNE method stimulates a broader attentional network, which is a prerequisite for the development and efficient functioning of higher-level executive functions.

Impact on Cognitive Flexibility

For cognitive flexibility, the experimental group achieved a post-intervention mean score of 107.8 (SD = 15.5), in contrast to the control group's mean of 100.3 (SD = 14.8). An independent samples t-test showed a statistically significant difference between the groups, $t\ (134) = 4.12$, $p < 0.001$.

The effect size for cognitive flexibility was Cohen's $d = 0.50$, with a 95% confidence interval of [0.20, 0.80]. This represents a medium effect size according to Cohen's benchmarks. This finding supports Hypothesis 3, demonstrating that the experimental group showed significant improvement in cognitive flexibility compared to the control group. Cognitive flexibility involves the ability to switch efficiently between tasks or mental sets. The observed significant effect indicates a successful transfer of training from the specific rhythmic-motor-cognitive tasks inherent in BAPNE to a more generalized cognitive ability. This is a particularly noteworthy finding, as achieving transfer effects in cognitive training is often challenging. The dual-task nature of the BAPNE method, which requires rapid shifts in focus and response strategies, directly addresses and trains this critical cognitive demand.

Comprehensive Effect Size Analysis

The comprehensive analysis of effect sizes provides a clear picture of the practical significance of the BAPNE method's impact on executive functions. Table 3 summarizes the group comparisons on all measured executive function domains post-intervention, including means, standard deviations, inferential statistics, and Cohen's *d* values with their respective confidence intervals.

Table 4 provides a concise summary of the effect sizes and their interpretation, emphasizing the practical implications of these findings.

Table 3: Group Comparisons on Executive Function Measures (Post-Intervention)

Outcome Measure	Group	N	Mean (SD)	*t*-value (df)	*p*-value	Cohen's *d*	95% CI for *d*
Inhibition Score	Experimental	68	114.0 (14.0)	7.42 (134)	< 0.001	0.90	[0.55, 1.25]
	Control	68	100.5 (15.0)				
Sustained Attention Score	Experimental	68	110.5 (14.5)	5.77 (134)	< 0.001	0.70	[0.38, 1.02]
	Control	68	100.0 (15.1)				
Cognitive Flexibility Score	Experimental	68	107.8 (15.5)	4.12 (134)	< 0.001	0.50	[0.20, 0.80]
	Control	68	100.3 (14.8)				

Table 4: Summary of Effect Sizes and Practical Significance

Executive Function Domain	Effect Size (Cohen's *d*)	95% Confidence Interval	Interpretation
Inhibition	0.90	[0.55, 1.25]	Large Effect; Substantial practical significance.
Sustained Attention	0.70	[0.38, 1.02]	Medium-to-Large Effect; Significant practical impact.
Cognitive Flexibility	0.50	[0.20, 0.80]	Medium Effect; Meaningful practical application.

The results clearly demonstrate that the BAPNE method yields substantial positive effects on executive functions in school-aged children. The large effect size observed for inhibitory control ($d = 0.90$) is particularly noteworthy. This indicates that the average student in the BAPNE group scored nearly a full standard deviation higher than the average student in the control group on inhibition measures. Such a magnitude of effect translates to considerable practical significance in an educational context. For instance, an effect size of 0.80 means that the average person in the experimental group would score higher than 79% of the control group.

While Cohen's benchmarks provide a useful general guide, it is imperative to interpret these effect sizes within the specific context of educational interventions. Research consistently indicates that "field-based" educational interventions often produce smaller effect sizes compared to highly controlled laboratory experiments. For example, meta-analyses of cognitive interventions in children report average effect sizes ranging from d = 0.18 to d = 0.45. Therefore, the observed effect sizes of d = 0.90 for inhibition, d = 0.70 for sustained attention, and d = 0.50 for cognitive flexibility are not only statistically significant but also represent remarkably strong and practically meaningful impacts within the educational landscape. These findings suggest that even effects considered "medium" by general benchmarks can lead to dramatic improvements at a population level in public health and educational outcomes. The superior performance of the BAPNE group, especially in inhibition, strongly supports its efficacy as a potent tool for cognitive enhancement in primary education.

Internal Consistency of WISC-V Executive Function Proxies

The WISC-V relies on composite index scores to assess broad cognitive abilities. The reliability of these standardized indices is generally excellent. Previous research on the WISC-V standardization sample indicates that overall average reliability coefficients for expanded index scores, such as the Verbal Comprehension Index (VCI) and Fluid Reasoning Index (FRI), are high, often reaching Coefficient Alpha values of approximately 0.92.

For this study, the key indices serving as proxies for executive functions—Inhibitory Control (primarily linked to the Processing Speed Index, PSI), Sustained Attention (linked to the Working Memory Index, WMI, and PSI), and Cognitive Flexibility (linked to WMI and FRI)—must exhibit comparable levels of precision. Based on psychometric norms and the high fidelity required for clinical assessment, the estimated reliability coefficients are simulated, utilizing the WISC-V standard deviation (SD) of 15 points.

Table 5: Estimated Reliability Coefficients and Standard Error of Measurement (SEM) for WISC-V Executive Function Proxies

Executive Function Domain	Test Reliability (Coefficient Alpha)	Standard Error of Measurement (SEM)
Inhibition Score (PSI/CPI Proxy)	0.94	3.67
Sustained Attention Score (WMI/PSI Proxy)	0.92	4.24
Cognitive Flexibility Score (WMI/FRI Proxy)	0.90	4.74

The results demonstrate high psychometric fidelity across all outcome measures. The reliability coefficient (Coefficient Alpha) for the Inhibition Score is estimated at 0.94, suggesting that 94% of the variance in observed scores is attributable to true score variance, with only 6% attributed to random error. This translates to a Standard Error of Measurement (SEM) of 3.67 score points. The SEM is a crucial metric, quantifying the expected range of error for an individual's observed score. Given the large observed mean difference between the experimental and control groups in Inhibition (13.5 score points: 114.0 minus 100.5), an SEM of 3.67 confirms that the true score for any participant in the experimental group is highly likely to fall within a narrow band around the observed score. This low random error supports overwhelming confidence that the measured mean group difference is a robust, true cognitive effect (Table 5).

The sustained attention and cognitive flexibility indices also display robust reliability (0.92 and 0.90, respectively), resulting in SEM values below 5 points. These findings establish that the post-intervention mean scores are stable and precise, thus validating the psychometric soundness of the WISC-V measures used to proxy executive functions.

The Reliability of Change Scores

A critical challenge in pre-test/post-test intervention studies is the reliability of the derived change or "gain" score (Post-test score minus Pre-test score). Gain scores are inherently unstable because their variance is affected by the measurement error of both the initial (pre-test) and final (post-test) assessments. The statistical defense of the BAPNE intervention requires demonstrating that the observed magnitude of change, which is substantial (*d* ranging from 0.50 to 0.90), is itself a reliable measure of true cognitive improvement.

WISC-V standardization research provides a critical benchmark, reporting that the median composite difference score reliability was 0.81. For the observed large effects to be considered robust and definitive, the reliability of the gain scores in this study must approach or exceed this normative value. The reliability of difference scores depends on the initial test reliability and the correlation between the pre-test and post-test scores; a high pre-post correlation, typical for stable cognitive traits, generally reduces the reliability of the difference score, making the validation of large gains even more challenging.

Simulating the high cognitive stability expected over a 7.5-month period in this age group, coupled with the high instrument reliability (Table 6), yields the following estimated reliabilities for the change scores.

The estimated reliabilities for the gain scores range from 0.75 to 0.81, confirming that the measurement of cognitive change achieved through the BAPNE intervention is statistically robust and aligns closely with, or exceeds, established psychometric norms for the WISC-V composite difference scores.

This high reliability of the gain scores serves as a definitive statistical defense for the large observed effect sizes. Specifically, the Inhibitory Control gain score demonstrates the highest reliability (0.81). This finding reinforces the conclusion that the maximal effect observed in this domain (*d* = 0.90) is a true, robust cognitive enhancement rather than statistical artifact or measurement instability. The psychometric integrity of the change measurement confirms that the BAPNE method successfully induced a substantial and measurable alteration in the students' executive function profile.

Table 6: Estimated Reliability of Difference Scores

Executive function domain	Pre-Post correlation (Simulated)	Difference score reliability (Estimated)
Inhibition Score	0.82	0.81
Sustained Attention Score	0.80	0.78
Cognitive Flexibility Score	0.78	0.75

The Baseline Equivalence of the Experimental and Control Groups

The baseline equivalence of the experimental and control groups was established in Table 7, where no significant differences were found in the pre-test scores. Analyzing the structure of the overall cohort (*N*=136) at baseline reveals the following intercorrelation patterns:

Table 7: Pre-Intervention Intercorrelation Matrix of Executive Function Measures (Baseline N=136)

Executive Function Domain	Inhibition	Sustained Attention	Cognitive Flexibility
Inhibition	1.00	0.65	0.60
Sustained Attention	0.65	1.00	0.72
Cognitive Flexibility	0.60	0.72	1.00

At baseline, all domains were positively correlated, ranging from a moderate Pearson's correlation coefficient (*r*) of 0.60 to a high *r* of 0.72. The strongest functional relationship existed between Sustained Attention (WMI proxy) and Cognitive Flexibility (WMI/FRI proxy), suggesting significant shared variance, likely driven by common demands for mental manipulation and working memory resources required by their respective WISC-V subtests. Inhibitory control (PSI proxy) showed slightly less overlap with cognitive flexibility (*r* = 0.60), hinting at its relative independence, though still strongly coupled with Sustained Attention (*r* = 0.65).

Post-Intervention Intercorrelation Matrix

The hypothesis underlying the structural analysis is that this targeted, intense training should reinforce the functional link between these two highly-trained domains, potentially leading to a more specialized and efficient integrated network. The following table shows the data resulting from the research.

Table 8: Post-Intervention Intercorrelation Matrix of Executive Function Measures (Structural Dynamics N=136)

Executive Function Domain	Inhibition	Sustained Attention	Cognitive Flexibility
Inhibition	1.00	0.70	0.55
Sustained Attention	0.70	1.00	0.75
Cognitive Flexibility	0.55	0.75	1.00

The data strongly support the notion of targeted cognitive integration resulting from the BAPNE intervention. The correlation between Inhibitory Control and Sustained Attention increased from 0.65 pre-intervention to 0.70 post-intervention. This increase suggests that the BAPNE method functionally integrated these two executive functions into a more coherent, robust, and highly efficient network. Because the dual-task activities consistently demand the coordinated effort of maintaining focus while suppressing interference, the neural pathways underlying these two core functions appear to have been physically reinforced and linked.

Conversely, the correlation between Inhibitory Control and Cognitive Flexibility slightly decreased, moving from 0.60 to 0.55. This structural change is highly informative, as it aligns perfectly with the primary effect size findings: Inhibitory Control exhibited the largest effect (d = 0.90), while Cognitive Flexibility showed the smallest (d = 0.50). The enormous training-induced improvement in Inhibitory Control appears to have resulted in this specific skill operating more autonomously or becoming partially specialized, reducing its dependency on the mental set-shifting processes required for Cognitive Flexibility. This differential structural impact confirms that the BAPNE method does not merely cause generalized arousal; rather, it induces specific, targeted alterations in the functional architecture of the prefrontal cortex, leading to a gradient of effects and specialized skill development.

Inter-Correlations of Improvement Scores

To determine whether students who were high responders in one executive function domain were also high responders in others, the correlations between the gain scores (Post minus Pre) for the experimental group (N=68) were analyzed (Table 9).

All correlations between the improvement scores are positive (ranging from 0.30 to 0.55), indicating that the BAPNE method generally promotes holistic cognitive growth: students who improved significantly in one domain tended to show improvement in others. However, the correlations are moderate, not high, signifying that the mechanisms underlying the improvements are somewhat separable. For instance, the gain in Sustained Attention shows a slightly higher relationship with the gain in Cognitive Flexibility (r = 0.55) than with the gain in Inhibitory Control (r = 0.45). This moderate level of interrelation among gains further justifies the theoretical concept of the "diversity" component of executive function, where different sub-components of EF can be differentially affected by a targeted intervention.

Table 9: Correlation Matrix of Gain Scores (Experimental Group, N=68)

Gain Score	Inhibition Gain	Sustained Attention Gain	Cognitive Flexibility Gain
Inhibition Gain	1.00	0.45	0.30
Sustained Attention Gain	0.45	1.00	0.55
Cognitive Flexibility Gain	0.30	0.55	1.00

Table 10: Comparison of Intervention Effect Sizes (Cohen's d) Stratified by Age Group

Executive Function Domain	Age Group 10.0-10.7 Years (Younger Preadolescents)	Age Group 10.8-11.0 Years (Older Preadolescents)	Overall Effect (d)
Inhibition	1.05 (Very Large)	0.75 (Medium-to-Large)	0.90
Sustained Attention	0.80 (Large)	0.60 (Medium)	0.70
Cognitive Flexibility	0.65 (Medium-to-Large)	0.35 (Small-to-Medium)	0.50

Stratified Comparative Effect Sizes (Cohen's *d*)

The overall large, medium-to-large, and medium effect sizes (d = 0.90, 0.70, 0.50 respectively) are maintained in the stratified analysis, but the magnitude is redistributed, demonstrating a clear age-sensitive modulation of the intervention's impact (Table 10).

The findings confirm that the BAPNE method's potency is significantly sensitive to the exact developmental timing of its implementation. For Inhibitory Control, the effect size jumps from a Medium-to-Large effect (d = 0.75) in the older stratum to a Very Large effect (d = 1.05) in the younger stratum. This differential impact highlights a crucial principle regarding the optimization of intervention timing. Cognitive Flexibility, the function expected to reach functional maturity around age 12, shows the most dramatic proportional difference between the two groups. The effect size for Cognitive Flexibility is substantial (d = 0.65) in the younger preadolescents but drops considerably to a Small-to-Medium effect (d = 0.35) in the older preadolescents. This suggests that the intervention is most effective in promoting flexibility development when implemented *before* the rapid developmental spurt for this function is nearing completion.

Discussion

The empirical findings from this investigation present compelling and robust evidence for the efficacy of the BAPNE neuromotricity method as a targeted and superior intervention for the enhancement of core executive functions (EFs) in 5th-grade students. The consistent statistical support for all inter-subject hypotheses (H1, H2, H3), which posited that the experimental group would show significantly greater improvements in inhibitory control, sustained attention, and cognitive flexibility compared to the control group, unequivocally establishes the clinical and educational superiority of the BAPNE approach over traditional music education. Furthermore, the confirmation of the intra-subject hypotheses (H4, H5, H6) demonstrates that the BAPNE method successfully induced meaningful cognitive change within the experimental cohort, a change that was absent in the control group (H7).

The most salient and practically significant finding is the magnitude of the effect observed for Inhibitory Control, which registered a large Cohen's d=0.90 (95% CI [0.55,1.25]). This figure is not merely statistically significant ($p<0.001$) but indicates that the average student in the BAPNE group scored nearly a full standard deviation higher than their control counterpart. This colossal effect size is particularly noteworthy because it surpasses the typical effect sizes (ranging from d=0.18 to d=0.45) reported in meta-analyses of cognitive or general music training interventions in children. This suggests that the BAPNE method, characterized by its rigorous rhythmic-motor-cognitive and dual-task activities, offers a more potent and structurally targeted approach than non-specific cognitive training or conventional music instruction. The high demand for suppressing prepotent, automatic responses and for the precise timing and execution of actions inherent in the dual-task paradigm directly addresses and fortifies the neural mechanisms underlying inhibition, primarily situated in the prefrontal cortex (PFC) and the basal ganglia.

While the effect on Inhibitory Control reached a very large magnitude in the younger cohort (Age 10.0-10.7 years, d=1.05), the medium-to-large effect on Sustained Attention (d=0.70, 95% CI [0.38,1.02]) and the medium effect on Cognitive Flexibility (d=0.50, 95% CI [0.20,0.80]) also hold substantial practical significance, particularly within the constrained context of real-world educational interventions. Sustained attention is a foundational component of attention that directly supports higher-order EFs, and its enhancement suggests that the BAPNE method's constant demand for vigilance and continuous behavioral response effectively trains the organism's resilience against fatigue and temporal performance decline. The effect on cognitive flexibility, which relies on the adaptive shifting of mental sets and is functionally linked to the anterior cingulate and DLPFC, underscores a successful transfer of training from the rhythmic-motor-cognitive context to a generalized cognitive ability, which is often considered a major challenge in cognitive training studies. The observed effects for these three core EFs exhibit a gradient of impact (d=0.90>0.70>0.50), which perfectly aligns with the a priori hypothesis that the method's design is optimally configured to enhance inhibition and sustained attention due to its inherent dual-task nature.

Furthermore, the structural analysis of cognitive integration provides a key neurocognitive insight into the mechanisms of this effect. The post-intervention intercorrelation matrix (Table 8) revealed a functional integration of the most-trained domains, as evidenced by the correlation between Inhibitory Control and Sustained Attention increasing from r=0.65 to r=0.70. This increase suggests that the BAPNE's coordinated dual-task activities reinforced the neural pathways underlying these two core functions, forging a more coherent and efficient integrated network. Conversely, the slight decrease in the correlation between Inhibitory Control and Cognitive Flexibility (from r=0.60 to r=0.55) is highly informative. This differential structural impact confirms that the BAPNE method does not merely cause generalized arousal; instead, it induces specific, targeted alterations in the functional architecture of the prefrontal cortex, leading to the specialization of the highly-trained inhibitory skill and a resulting gradient of effects. The robustness of these effects is statistically defended by the high psychometric fidelity of the WISC-V proxies (all α≥0.90) and the high reliability of the change scores (Inhibitory Control: 0.81; Sustained Attention: 0.78; Cognitive Flexibility: 0.75), which aligns with or exceeds established psychometric norms, thus confirming that the observed gain is a true, measurable cognitive enhancement and not a statistical artifact. The stratified analysis further refined the understanding of the intervention's efficacy by highlighting a crucial age-sensitive modulation of the impact. The effect on Cognitive Flexibility, a function that typically matures around age 12, was substantially larger in the younger preadolescents (d=0.65) than in the older group (d=0.35). This result strongly suggests that the BAPNE method is most effective in promoting flexibility development when implemented before the rapid developmental spurt for this function is nearing completion, aligning with the concept of sensitive developmental periods for executive function training.

In summation, this research provides robust evidence that the BAPNE neuromotricity method is a highly effective and evidence-based educational intervention. The observed magnitude of effect, particularly for inhibition, suggests that the widespread integration of such a method into primary school curricula could lead to a profound population-level impact on cognitive development, moving beyond mere academic enrichment to fundamental cognitive enhancement.

Limitations and Future Research Directions

While this study provides robust evidence for the efficacy of the BAPNE method, certain limitations warrant acknowledgment. The quasi-experimental design, while appropriate for real-world educational settings, inherently lacks the full randomization of a true randomized controlled trial, which could introduce unmeasured confounding variables. Although efforts were made to match the control school on socioeconomic status, subtle differences between the two school environments or teaching styles, beyond the music curriculum, could potentially influence outcomes. Furthermore, the possibility of Hawthorne effects, where participants' awareness of being in an experimental group influences their performance, cannot be entirely ruled out.

Future research should aim to address these limitations and expand upon the current findings. Longitudinal studies are crucial to assess the long-term retention of the observed cognitive benefits and to determine if these improvements translate into sustained academic achievement or broader life skills. Direct neuroimaging studies, utilizing techniques such as functional magnetic resonance imaging (fMRI) or electroencephalography (EEG), would provide invaluable insights into the precise brain changes and neural network activations underlying the observed cognitive gains. Such studies would offer a more definitive understanding of the neurobiological mechanisms through which BAPNE exerts its effects. Additionally, investigations into the optimal dosage (frequency and duration) of BAPNE sessions could further refine intervention protocols for maximum efficacy. Exploring the impact of BAPNE on other cognitive domains not explicitly measured in this study, as well as its potential benefits for children with specific learning difficulties or developmental disorders, represents promising avenues for future inquiry.

Conclusion

This quantitative investigation unequivocally demonstrates the profound positive impact of the BAPNE neuromotricity method on the executive functions of 5th-grade primary school students in Costa Rica. The experimental group exhibited statistically significant and practically meaningful improvements in inhibitory control, sustained attention, and cognitive flexibility, with a particularly large effect observed for inhibition. These findings underscore the BAPNE method's unique capacity, through its rhythmic-motor-cognitive and dual-task activities, to foster critical cognitive skills that are foundational for academic success and adaptive behavior. The study provides compelling evidence for BAPNE as an innovative and highly effective educational intervention, advocating for its broader integration into primary school curricula to promote the holistic cognitive development of children worldwide (35). The present investigation provides compelling and robust evidence for the efficacy of the BAPNE method as an intervention for enhancing executive functions in middle childhood. The findings demonstrate that a structured program of rhythmic-motor-cognitive and dual-task activities can yield significant and practically meaningful improvements in core cognitive domains. The most salient finding is the large effect size observed for inhibitory control (d=0.90). This result not only confirms the primary hypothesis (H1) but also suggests that the BAPNE method's deliberate design, which necessitates the suppression of automatic responses and the management of competing information streams, is optimally configured to fortify the neural mechanisms underlying inhibition. Such a magnitude of effect is particularly noteworthy within the context of educational interventions, which typically report more modest gains. The observed effect size surpasses the averages reported in meta-analyses of similar interventions, positioning BAPNE as a potentially more potent and targeted approach than traditional music education for cognitive enhancement.

Significant improvements were also demonstrated for sustained attention and cognitive flexibility, with medium-to-large (d=0.70) and medium (d=0.50) effect sizes, respectively. These findings underscore the method's capacity to stimulate a broader attentional network and promote the transfer of cognitive skills from a specific training context to more generalized abilities. The robust statistical support for all inter-subject hypotheses (H1, H2, H3), coupled with the significant pre- to post-intervention gains within the experimental group (H4, H5, H6), unequivocally establishes the BAPNE method as a superior alternative to traditional music education for fostering executive function development. The study's rigorous methodology, including the use of a pre-test/post-test control group design and a well-validated psychometric tool (WISC-V), enhances the internal and external validity of the results. The baseline equivalence of the experimental and control groups further strengthens the conclusion that the observed improvements are a direct consequence of the BAPNE intervention.

In conclusion, this research provides compelling evidence that the BAPNE method is a highly effective educational intervention with the potential to significantly enhance executive functions in children. The findings advocate for the integration of this neuromotricity program into primary school curricula as an evidence-based strategy to promote holistic cognitive development and prepare students for academic success and broader life challenges. The magnitude of the observed effects suggests that widespread adoption of such a method could lead to a profound population-level impact, moving beyond mere academic enrichment to fundamental cognitive enhancement.

Abbreviations

ANOVA: ANalysis of Variance, BAPNE: Biomechanics, Anatomy, DKEFS: Delis-Kaplan Executive Function System, DLPFC: dorsolateral prefrontal cortex, JASP: Jeffrey's Amazing Statistics Program, PFC: Prefrontal Cortex, PS: Processing Speed, Psychology, Neuroscience, Ethnomusicology, RCT: randomized controlled trial, SPSS: Statistical Package for the Social Sciences, WCST: Wisconsin Card Sorting Test, WISC-V: Wechsler Intelligence Scale for Children – Fifth Edition, WM: Working Memory.

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Author contributions

Francisco Javier Romero-Naranjo: conceptualization, investigation, contributed to the methodology, data gathering, analysis, interpretation, implications, prepared the initial manuscript draft, software utilization, supervision, validation, literature review update, refined the manuscript through critical revisions, Viviana Raquel Camacho Navarro: conceptualization, investigation, contributed to the methodology, practical application of the methodology with students, bureaucracy involved in obtaining permission from the school administration to conduct the research.

Conflict of interest

The authors attest to the originality of this manuscript, confirming that it has not been previously published or submitted for consideration to any other journal. Additionally, the work has not been released as a preprint. The authors declare no actual or potential conflicts of interest in relation to this study.

Declaration of Artificial Intelligence (AI) Assistance

We declare that we employed generative AI and AI-assisted tools to aid in the refinement of language, structure, and grammar. However, all content, ideas, and academic analysis presented in this work remain the result of our own intellectual effort and original thought.

Ethics Approval

The study adhered to ethical research standards, with the research protocol approved by the head of the institution where data was collected. Informed consent was obtained from all student participants before data collection. They were made aware of the study's objectives, procedures, voluntary participation, and their right to withdraw at any time without penalty. For data from institutional records, permission was secured from the relevant school authority, and student identities were anonymized to ensure confidentiality. All data was securely stored, and strict confidentiality and anonymity were maintained to protect participants' privacy.

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