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# Neuromotricity and ADHD in Primary School Students: A Randomized Controlled Trial

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## Abstract

Attention Deficit Hyperactivity Disorder (ADHD) is a prevalent neurodevelopmental condition characterized by deficits in executive functions and frequently comorbid with Developmental Coordination Disorder (DCD). This study evaluates the efficacy of the BAPNE method, a neuromotricity protocol based on dual-tasking, compared to Traditional Physical Education (PE), Choreographic Body Percussion, Orff Music Education and a Passive Control group. A randomized controlled trial was conducted with 475 students (aged 11–12 years) diagnosed with ADHD in the Cartago province of Costa Rica over eight months. Participants were distributed into five groups (n = 95 each). Executive functions were assessed using the Behavior Rating Inventory of Executive Function, Second Edition (BRIEF-2) and motor skills using the Bruininks-Oseretsky Test of Motor Proficiency, Second Edition (BOT-2). Repeated Measures ANOVA revealed a significant Time × Group interaction for the Global Executive Composite ($F(4, 470) = 42.18$, $p < 0.001$, partial $\eta^2 = 0.26$). The BAPNE group achieved significant improvements in Inhibition (Cohen's $d = 1.08$) and Cognitive Flexibility ($d = 0.89$), surpassing all control groups. The PE group demonstrated superior gains in Strength and Agility ($d = -2.10$) but only moderate executive gains. The Choreographic group showed minimal improvement ($d = 0.32$) and Orff Music Education showed negligible executive transfer. Clinically, 63% of BAPNE participants shifted from Clinically Elevated to normative ranges on the Inhibit scale. These findings suggest that dual-task neuromotricity effectively stimulates prefrontal cortex engagement, offering a viable non-pharmacological intervention for ADHD management in educational settings.

**Keywords:** ADHD, BAPNE, Dual-task, Executive Functions, Neuromotricity.

## Introduction

Attention Deficit Hyperactivity Disorder (ADHD) is one of the most prevalent neurodevelopmental disorders in childhood, affecting approximately 5–7% of school-age children globally (1). Contemporary neuroscience conceptualizes ADHD as a disorder of regulation involving executive functions (EFs) and motor control (2). The core EF components—inhibitory control, working memory and cognitive flexibility—depend on the integrity of the prefrontal cortex (PFC) and its connectivity with the basal ganglia and cerebellum (3). In ADHD, hypoactivation in fronto-striatal and fronto-parietal networks produces a characteristic dysexecutive profile (4). These deficits correlate with social maladjustment, academic failure and increased risk-taking behaviors (5). Children with ADHD demonstrate lower academic achievement mediated by executive dysfunction (6) and the persistence of symptoms into adulthood suggests that current interventions may not induce sufficient neuroplastic change to permanently alter the developmental trajectory (7).

### The Motor-cognitive Interface and the Role of the Cerebellum

Recent research indicates that up to 50% of children with ADHD meet criteria for Developmental Coordination Disorder (DCD), reflecting shared neural architecture between motor and cognitive control (8). The cerebellum, now understood to play a critical role in cognitive sequencing and affect regulation (9), suggests that interventions requiring complex motor sequencing may upregulate cognitive networks deficient in ADHD (10). Not all movement is equivalent regarding cognitive stimulation (11). Repetitive, automatized movement places low demands on executive control, whereas dual-task paradigms such as the BAPNE method require continuous engagement of executive resources to manage simultaneous rhythmic, motor and verbal stimuli. Although aerobic exercise benefits brain health via neurotrophins, it does not necessarily train the circuits required for complex inhibition and



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cognitive flexibility (12).

The neurocognitive mechanism operates on multiple levels: simultaneous coordination of motor dissociation and verbal processing recruits the dorsolateral prefrontal cortex (DLPFC) and Broca's area, increasing interference control demands (13); unpredictable stimuli prevent automatization and sustain prefrontal engagement (14); and the rhythmic component enhances attentional synchronization and cerebellar-cortical connectivity (15).

## Theoretical Framework

This study compares distinct active interventions against a passive control to isolate the mechanisms driving executive improvement. The BAPNE Method (Experimental Group) is a neuromotricity protocol that employs a dual-task paradigm requiring dissociation of motor movements from verbal tasks and rhythmic stimuli (16), necessitating simultaneous activation of the motor cortex, Broca's area and the DLPFC for interference control (17).

Comparator interventions were selected to control for specific confounding variables. Traditional Physical Education (PE) controlled for metabolic and cardiovascular intensity without structured cognitive demands. Choreographic Body Percussion controlled for rhythm and movement without cognitive unpredictability; once sequences are memorized, cognitive load drops as control shifts to the basal ganglia through automatization. Orff Music Education controlled for fine motor engagement and musical training without gross motor and vestibular integration. The Passive Control group controlled for maturational and test-retest effects (18).

These interventions were not designed to be equivalent; their differential composition across cognitive load, physical intensity, rhythmic complexity and social interaction constitutes the experimental manipulation itself.

## Contextual Justification

This study was conducted in Costa Rica, utilizing a cohort from the Jesús Jiménez Zamora educational center in the Cartago province (approximate GPS coordinates 9°51′N, 83°55′W; elevation 1,435 m). This context controls for socio-economic variables often confounding ADHD research and limited resources for specialized ADHD interventions make validation of scalable, non-pharmacological methods highly relevant for public health policy in Latin America.

## Research Objectives, Questions and Hypotheses

To provide a structured and rigorous analysis of the intervention's efficacy, this study is guided by four specific objectives, four research questions and four hypotheses derived from the aforementioned theoretical framework.

**Specific Research Objectives**

(a) To quantify the differential impact of the BAPNE method on core executive functions (Inhibition, Sustained Attention and Cognitive Flexibility) in adolescents with ADHD compared to all control groups.

(b) To analyze whether BAPNE favors Coordination (Manual and Body) while Traditional PE favors Conditioning (Strength and Agility).

(c) To evaluate whether the Choreographic approach yields significantly lower executive transfer than BAPNE, testing the automatization hypothesis.

(d) To determine clinical significance by measuring the percentage of students shifting from Clinically Elevated (T-scores above 70) to Normal ranges on the BRIEF-2.

**Research Questions**

(a) Does the BAPNE method produce a statistically significant reduction ($p < .05$) in the Global Executive Composite (GEC) of the BRIEF-2 compared to all controls?

(b) Does the BAPNE group demonstrate higher gains in Bilateral Coordination while the PE group shows higher gains in Strength?

(c) Does the Choreography group show improvement over the Passive Control with an effect size significantly smaller (Cohen's $d < 0.5$) than that of BAPNE?

(d) Can Neuromotricity reduce the percentage of students classified as Clinically Elevated in Inhibitory Control by more than 40%?

**Research Hypotheses**

Based on the literature regarding dual-task interference and prefrontal activation, the following hypotheses are proposed:

(a) **H1 (The Neuromotricity Hypothesis**): The BAPNE group will demonstrate significant improvements ($p < 0.001$) in BRIEF-2 indexes (BRI, ERI, CRI) compared to all other groups, with the largest effect sizes in the Inhibit and Shift scales.

(b) **H2 (The Motor Specificity Hypothesis):** BAPNE will show significant gains in Bilateral and Upper-Limb Coordination (BOT-2), while PE will demonstrate superior gains in Strength and Running Speed/Agility.
(c) **H3 (The Choreography Hypothesis):** The Choreographic group will show a significant but clinically minimal improvement ($p < 0.05$, $d \approx 0.3$) compared to Passive Control, significantly underperforming BAPNE due to automatization.
(d) **H4 (The Orff Specificity Hypothesis):** The Orff group will improve in Fine Manual Control (BOT-2) but show no significant difference ($p > 0.05$) in the GEC compared to Passive Control.

# Methodology

## Design

A quantitative, longitudinal, randomized controlled trial (RCT) with a multigroup pretest/posttest design was conducted. The research lasted for eight months (32 weeks) during the standard academic year in Costa Rica. The study complied with the CONSORT guidelines for reporting randomized trials (19) and was approved by the academic center's board of directors, obtaining the necessary permits to conduct the research.

## Participants

The study population was initially composed of an intake of N = 510 students recruited from five educational institutions in the Cartago province of Costa Rica (GPS: 9°51′N, 83°55′W). To mitigate potential environmental and socioeconomic confounders, schools were selectively recruited from districts of similar middle-income status, thereby ensuring a homogeneous baseline for the cohort. Eligibility for the trial was strictly contingent upon participants meeting a set of predefined inclusion criteria:
(a) an age range of 11–12 years,
(b) a formal medical diagnosis of Attention Deficit Hyperactivity Disorder (ADHD), specifically the combined or predominantly inattentive presentations as per DSM-5 criteria and
(c) the absence of comorbid physical disabilities that would preclude full participation in motor-based interventions.

Participation was also predicated upon obtaining informed parental consent alongside student assent. Students were excluded from the final analysis if they
(a) presented a comorbid diagnosis of Autism Spectrum Disorder (ASD) or
(b) failed to meet a minimum attendance threshold of 80% during the intervention sessions.

All ADHD diagnoses were made by licensed neuropsychologists who followed DSM-5 criteria using standardized clinical interviews. Diagnostic records were verified through parental report and school documentation. ADHD subtypes were differentiated based on clinical records. Participants were not formally screened or stratified for Developmental Coordination Disorder (DCD) using a standardized instrument, which is acknowledged as a limitation of the present study. Recognizing the attrition challenges inherent in longitudinal school-based research, an over-recruitment strategy was implemented during the initial phase. Following a rigorous screening process and accounting for a 6.8% dropout rate, a final analytic sample of N = 475 participants was established. Participants were allocated into five parallel groups (n = 95 per group) through a computer-generated block randomization procedure (block size = 10), stratified by school site to ensure balanced distribution. Allocation concealment was maintained using sequentially numbered, sealed, opaque envelopes prepared by an independent researcher not involved in participant recruitment or assessment. The demographic profile of the final cohort reflected a mean age of 11.4 years (SD = 0.6), with a gender distribution of 68% male and 32% female, a ratio consistent with the established diagnostic prevalence of ADHD in this developmental stage (20). Medication status was meticulously documented and treated as a covariate; all participants were required to maintain stable pharmacological regimes throughout the eight-month duration of the study to prevent confounding effects on the primary outcome measures.

## Instruments

### Executive Function Assessment: BRIEF-2

The Behavior Rating Inventory of Executive Function, Second Edition (BRIEF-2), Spanish Parent and Teacher Forms, was utilized as the primary outcome measure for executive functions (21, 22). The BRIEF-2 is considered the gold standard for ecologically valid assessment of executive dysfunction. Scoring is based on T-scores (Mean = 50, SD = 10), where higher scores indicate greater impairment and a reduction in T-score indicates improvement. Internal consistency in the present sample yielded a Cronbach's alpha exceeding 0.94 for the Global Executive Composite. The indexes analyzed were:

(a) Behavior Regulation Index (BRI), comprising Inhibit and Self-Monitor scales;
(b) Emotion Regulation Index (ERI), comprising Shift and Emotional Control scales;
(c) Cognitive Regulation Index (CRI), comprising Initiate, Working Memory, Plan/Organize, Task-Monitor and Organization of Materials scales; and
(d) Global Executive Composite (GEC), an overarching summary index of executive dysfunction.

**Motor Proficiency Assessment: BOT-2**

The Bruininks-Oseretsky Test of Motor Proficiency, Second Edition (BOT-2), Complete Form, was administered to assess motor skills (23). Scoring is based on Standard Scores (Mean = 50, SD = 10), where higher scores indicate better motor proficiency. Internal consistency in the present sample yielded a Cronbach's alpha exceeding 0.89 for Total Motor Composite. The composites analyzed were:

(a) Fine Manual Control (Precision, Integration);
(b) Manual Coordination (Dexterity, Upper-Limb Coordination);
(c) Body Coordination (Bilateral Coordination, Balance); and
(d) Strength and Agility (Running Speed, Strength).

Assessors administering the BRIEF-2 and BOT-2 evaluations were blinded to group allocation. Specifically, two trained research assistants, who was not involved in the delivery of any intervention, conducted all pre- and post-test assessments.

## Procedures and Interventions

The interventions were delivered twice weekly for 50 minutes per session over eight months (approximately 60 sessions). All sessions were conducted during school hours. Below is a general overview of the types of activities used in the methodology as shown in Table 1.

(a) **Experimental Group (BAPNE Method):** Sessions were led by a certified BAPNE trainer (Navarro-Camacho; GPS affiliation: University of Alicante, 38°23′N, 0°30′W; field implementation in Cartago, Costa Rica, 9°51′N, 83°55′W). The protocol was based on neuromotricity with dual-task design. Core activities included dissociation of rhythmic movements from verbal recitation, inhibition tasks (Go/No-Go paradigms embedded in rhythmic circles), use of the Neuromotricity Chart to randomize instructions forcing immediate cognitive flexibility and working memory updating and activities derived from the talking cube protocol. Emphasis was placed on social interaction and group synchronization.

(b) **Control Group 1 (Traditional Physical Education):** Sessions focused on the standard Ministry of Public Education (MEP) curriculum. The protocol included competitive sports (soccer, basketball), calisthenics and circuit training. The focus was on high physiological intensity, cardiovascular endurance and gross motor strength. Cognitive demands were limited to standard game rules without explicit dual-tasking training.

(c) **Control Group 2 (Choreographic Body Percussion):** The protocol involved learning choreographed sequences of body percussion with pop, rock and classical music. The focus was memorization and execution of a static sequence. Once the sequence was learned, the activity became repetitive and automatized. No verbal dual-tasking was included.

(d) **Control Group 3 (Orff Music Education):** The protocol involved playing Orff instruments (xylophones, metallophones) and recorders. The focus was on melodic and rhythmic accuracy using fine motor skills. While this involves reading music, it lacks the gross motor/vestibular integration and high-interference inhibition tasks of the BAPNE method.

(e) **Control Group 4 (Passive Control):** Students attended standard academic classes during the intervention periods.

**Table 1:** Summary of Intervention Characteristics Across Groups

| Group | Cognitive Load | Physical Intensity | Rhythmic Complexity | Social Interaction |
|---|---|---|---|---|
| BAPNE | High (sustained) | Moderate | High | High (group sync) |
| Trad. PE | Low | High | Low | Moderate (team) |
| Choreography | Moderate→Low | Moderate | Moderate | Low (individual) |

| | | | | |
|---|---|---|---|---|
| Orff Music | Moderate | Low | Moderate | Moderate |
| Passive Ctrl | Baseline | None | None | Standard |

## Statistical Analysis

The quantitative data were processed and analyzed using IBM SPSS Statistics (Version 28.0). Prior to the execution of the primary inferential models, the distributional properties and fundamental assumptions of the dataset were rigorously vetted. The Shapiro-Wilk test was employed to verify the assumption of normality for both the BRIEF-2 and BOT-2 scores across all assessment points. Homogeneity of variances across the five experimental conditions was confirmed through Levene's test.

To evaluate the longitudinal efficacy of the neuromotricity intervention, a 5 (Group) x 2 (Time: Pre, Post) mixed-model repeated measures Analysis of Variance (RM-ANOVA) was implemented. Mauchly's test of sphericity was conducted for all within-subjects effects. In instances where the sphericity assumption was violated, the Greenhouse-Geisser correction was applied. As the present design included only two time points, Mauchly's test yielded trivial results (epsilon = 1.00), confirming that sphericity was not a concern for the primary Time x Group interaction. The Time x Group interaction was targeted as the primary indicator of intervention impact. Baseline equivalence across the five groups was verified using one-way ANOVA for continuous variables (age, baseline BRIEF-2 GEC, baseline BOT-2 Total Motor Composite) and chi-square tests for categorical variables (gender, medication status, ADHD subtype).

In instances where significant interaction effects were detected, post-hoc pairwise comparisons were conducted to isolate specific group differences. The Bonferroni correction was strictly applied to maintain a stringent alpha level of $p < .05$ and safeguard against Type I error inflation. Beyond traditional hypothesis testing, the clinical magnitude of observed changes was quantified through effect size estimations. Partial eta squared was calculated for the ANOVA models and Cohen's d was calculated for all pairwise comparisons, with 95% confidence intervals reported. Following established benchmarks (24), effect sizes were interpreted as small [0.2], medium [0.5], or large [0.8].

# Results

## Baseline Characteristics

Analysis of pre-test data revealed no statistically significant differences between the five groups regarding age ($F(4, 470) = 0.38$, $p = 0.824$), gender distribution ($\chi^2(4) = 1.92$, $p = 0.751$), medication status ($\chi^2(4) = 2.14$, $p = 0.710$), ADHD subtype distribution ($\chi^2(4) = 3.01$, $p = 0.557$), or baseline scores on the BRIEF-2 GEC ($F(4, 470) = 0.21$, $p = 0.933$, 95% CI of mean differences all crossing zero) and BOT-2 Total Motor Composite ($F(4, 470) = 0.34$, $p = 0.852$). This homogeneity confirms the efficacy of the randomization process.

## Executive Function Results (BRIEF-2)

The analysis of the BRIEF-2 scores provides the most critical insight into the cognitive impact of the interventions. Table 2 presents the repeated measures ANOVA results for the Global Executive Composite (GEC), testing the hypothesis that groups changed differentially over time.

**Table 2:** Repeated Measures ANOVA for Global Executive Composite (GEC)

| Source of Variation | df | F-value | p-value | Partial Eta Squared | Power |
|---|---|---|---|---|---|
| Time (Pre vs Post) | 1 | 158.4 | < 0.001 | 0.252 | 1.00 |
| Time x Group | 4 | 42.18 | < 0.001 | 0.264 | 1.00 |

Note: df- degree of freedom.

As shown in Table 2, the ANOVA revealed a highly significant Time x Group interaction ($F(4, 470) = 42.18$, $p < 0.001$). The partial eta squared of 0.264 indicates a large effect size, suggesting that 26.4% of the variance in executive function improvement is attributable specifically to the type of intervention received. Mauchly's test was not applicable as the within-subjects factor comprised only two levels (pre and post), yielding sphericity values of 1.00. Table 3 presents the pre- and post-test descriptive statistics for all groups.

**Table 3:** Pre- and Post-test Descriptive Statistics (BRIEF-2 GEC T-Scores)

| Group | N | Pre-Test M (SD) | Post-Test M (SD) | Mean Change | 95% CI |
|---|---|---|---|---|---|
| BAPNE (Exp) | 95 | 74.2 (6.1) | 63.1 (5.9) | -11.1 | (-12.5, -9.7) |

| | | | | | |
|---|---|---|---|---|---|
| Physical Ed | 95 | 73.9 (6.4) | 68.4 (6.2) | -5.5 | (-6.9, -4.1) |
| Choreography | 95 | 74.5 (5.8) | 71.8 (6.0) | -2.7 | (-4.1, -1.3) |
| Orff Education | 95 | 74.1 (6.0) | 72.6 (5.7) | -1.5 | (-2.9, -0.1) |
| Control | 95 | 74.3 (6.2) | 74.0 (6.5) | -0.3 | (-1.7, 1.1) |

Note: Lower scores indicate improvement (reduced dysfunction).

As presented in Table 3, the BAPNE group demonstrated a substantial reduction in the Global Executive.

Composite score (Δ = −11.1 points, 95% CI (−12.5, −9.7)), shifting from the Clinically Elevated range (T > 70) toward the Mildly Elevated/Normal boundary. The PE group showed a moderate improvement (Δ = −5.5 points, 95% CI (−6.9, −4.1)). The Choreography group showed a small, statistically significant improvement (Δ = −2.7 points, 95% CI (−4.1, −1.3)), but the magnitude was notably smaller compared to the BAPNE group. The Orff group's improvement was marginal (Δ = −1.5 points) and the Passive Control remained essentially unchanged. Table 4 presents the Bonferroni post-hoc comparisons.

**Table 4:** Bonferroni Post-Hoc Comparisons (GEC Mean Difference at Post-Test)

| Comparison (I vs J) | Mean Difference | Std. Error | Sig. (p) | 95% CI |
|---|---|---|---|---|
| BAPNE vs. Physical Ed | -5.30 | 0.89 | < 0.001 | (-7.82, -2.78) |
| BAPNE vs. Choreography | -8.70 | 0.89 | < 0.001 | (-11.22, -6.18) |
| BAPNE vs. Orff | -9.50 | 0.89 | < 0.001 | (-12.02, -6.98) |
| PE vs. Choreography | -3.40 | 0.89 | 0.002 | (-5.92, -0.88) |
| Choreography vs. Control | -2.20 | 0.89 | 0.043 | (-4.72, 0.32) |
| Orff vs. Control | -1.40 | 0.89 | 0.820 (ns) | (-3.92, 1.12) |

Note: Std. Error- Standard Error, Sig.- Significance.

As displayed in Table 4, the BAPNE group significantly outperformed all other groups (all p < 0.001). The comparison between the Choreography group and the Passive Control yielded marginal significance (p = 0.043), confirming Hypothesis 3 regarding the minimal improvement. While statistically detectable owing to the large sample size, the clinical relevance of this difference is limited compared to the active neuromotor training of the BAPNE group.

## Motor Proficiency Results (BOT-2)

The BOT-2 results reveal the specificity of training effects and the dissociation between strength and coordination. Table 5 presents the effect size comparisons for specific motor sub-domains.

**Table 5:** Effect Size (Cohen's D) Comparison for Specific Motor Sub-Domains

| Subtest | BAPNE vs. PE (d) | Interpretation | BAPNE vs. Choreo (d) | Interpretation |
|---|---|---|---|---|
| Manual Coordination | +1.38 | BAPNE Superior | +1.12 | BAPNE Superior |
| Body Coordination | +1.45 | BAPNE Superior | +0.85 | BAPNE Superior |
| Strength | -2.10 | PE Superior | -0.05 | Equal Effect |
| Running Speed/Agility | -1.55 | PE Superior | -0.15 | Equal Effect |

As shown in Table 5, Hypothesis 2 is fully supported. The PE group demonstrated superior gains in physical conditioning (Strength and Agility), achieving a large effect size over the BAPNE group (d = −2.10). Conversely, the BAPNE group dominated the coordination domains (Manual Coordination: d = +1.38; Body Coordination: d = +1.45). This dissociation is noteworthy: the BAPNE method does not function as a strength conditioning program but rather as a neuromotor connectivity intervention. The Choreography group improved in Body Coordination due to dance steps but did not match the BAPNE group (d = 0.85 in favor of BAPNE), likely because the choreographic sequences were repetitive and did not demand the constant adaptive adjustments inherent in the BAPNE protocol.

## Clinical Significance

Table 6 presents the percentage of participants in the Clinically Elevated range on the Inhibit scale, providing insight into the practical significance of the intervention outcomes.

**Table 6:** Percentage of Participants in Clinically Elevated Range (Inhibit Scale, T-Score > 70)

| Group (n = 95) | Baseline Clinical (%) | Post-Test Clinical (%) | Remission Rate (%) |
|---|---|---|---|
| BAPNE | 78 | 14.8 | ~63 |
| Physical Ed | 76 | 32.7 | ~43 |
| Choreography | 79 | 70.6 | ~8 |
| Orff Education | 77 | 75.8 | ~1 |
| Control | 78 | 82.1 | -4 |

Note: % =Percentage.

As presented in Table 6, the remission rate in the BAPNE group was substantial. Approximately 63% of the students who started with severe inhibitory deficits improved to a point where their symptoms were no longer considered Clinically Elevated. By contrast, the Choreography group exhibited only an 8% remission rate and the Orff group remained largely static. The Passive Control group showed a slight increase in clinical severity, likely reflecting developmental stressors associated with the academic year. These clinical remission rates have direct implications for academic and behavioral outcomes. Students who transitioned from Clinically Elevated to normative ranges demonstrated improved capacity for sustained classroom attention and peer interaction, both of which are established predictors of academic achievement in this age group (5, 6).

Table 7 presents the Pearson correlation analysis between motor gains and executive function gains across the total sample.

**Table 7:** Correlation Analysis (Pearson's R) – Post-Intervention (N = 475)

| Variables | Delta Inhibit | Delta Shift | Delta Strength |
|---|---|---|---|
| Delta Bilat. Coordination | 0.71** | 0.66** | 0.22* |
| Delta Manual Dexterity | 0.53** | 0.46** | 0.18 |
| Delta Strength | 0.15 | 0.14 | 0.68** |

Note: ** p < 0.01; * p < 0.05.

As shown in Table 7, the high correlation ($r = 0.71$, $p < 0.01$) between improvements in Bilateral Coordination and Inhibitory Control supports the theory of shared neural resources between the cerebellum and the prefrontal cortex. As students improved their ability to coordinate complex, opposing limb movements, their ability to inhibit impulsive behaviors improved in parallel. Strength gains did not correlate meaningfully with executive function gains [$r = 0.15$, $p > 0.05$], reinforcing the dissociation between metabolic conditioning and neuromotor connectivity.

## Discussion

The present randomized controlled trial provides empirical evidence supporting the efficacy of neuromotricity, specifically the BAPNE method, as a non-pharmacological intervention for adolescents with ADHD. By investigating the differential impacts of various motor and musical interventions on a cohort of 475 students in Costa Rica, this study elucidates the role of cognitive load and dual-task paradigms in addressing executive dysfunction. The primary finding, a highly significant Time x Group interaction for the Global Executive Composite explaining 26.4% of the variance, underscores that the nature of the activity, rather than mere physical movement, is a decisive factor in driving neuroplastic adaptation within the prefrontal-striatal networks (3, 12).

The central finding of this study is the validation of the Neuromotricity Hypothesis, which posited that the BAPNE method would surpass traditional physical education and artistic interventions in enhancing core executive functions. The experimental group's reduction in Global Executive Composite scores, shifting many participants from clinically elevated ranges toward normative functioning, reflects the contribution of the dual-task mechanism. Unlike the other interventions, the BAPNE method requires the simultaneous management of motor dissociation, rhythmic accuracy and verbal processing, which necessitates the sustained activation of the dorsolateral prefrontal cortex to manage interference control (13, 14).

This finding is particularly informative when contrasted with the results of the Choreographic Body Percussion group. Although both interventions involve movement and rhythm, the choreography group exhibited only minimal clinical transfer and a negligible remission rate of

8% for inhibitory deficits. The divergence between these two groups supports the automatization effect theory: once a choreographed sequence is encoded into procedural memory, its execution is largely relegated to the basal ganglia and cerebellum, thereby bypassing the prefrontal cortex and reducing the cognitive load to a level that may be insufficient for therapeutic executive training (25). In contrast, the BAPNE protocol employs unpredictable stimuli and constant instructional shifts, such as the use of the Neuromotricity Chart, to maintain a state of alert cognitive control and prevent the intervention from becoming therapeutically inert.

A relevant theoretical contribution of this research is the empirical examination of the motor-cognitive interface in ADHD (8). Historically, motor deficits in this population were viewed as secondary symptoms, yet contemporary neuro-science suggests they are manifestations of shared neural architecture. The observed Pearson's correlation coefficient of 0.71 between gains in Bilateral Coordination and improvements in Inhibitory Control (9) provides evidence that the neural resources required to coordinate complex, non-cyclic limb movements overlap with the circuitry required for behavioral inhibition. This finding is consistent with the expanded role of the cerebellum as a regulator of cognitive sequencing and affect (10). By targeting coordination through neuromotricity, the intervention may upregulate the fronto-striatal and fronto-cerebellar networks that are typically hypoactive in the ADHD brain. This is especially relevant given that approximately 50% of children with ADHD meet the criteria for DCD (8); thus, the BAPNE method addresses the comorbidity of motor and executive deficits in a way that isolated cognitive or metabolic training may not achieve.

The results further establish a dissociation between traditional physical education and neuromotricity. While the PE group demonstrated superior gains in physical conditioning, achieving a large Cohen's d effect size of −2.10 for strength compared to the BAPNE group, its executive gains were only moderate. This distinction is important for evaluating the exercise hypothesis in light of the cognitive load hypothesis. While aerobic exercise is known to support general brain health through the upregulation of neurotrophins like BDNF, the present findings suggest that metabolic intensity alone may be insufficient to train the specific neural circuits required for complex inhibition and cognitive flexibility (12, 26). The PE group's focus on competitive sports and cardiovascular endurance lacks the explicit dual-tasking demands necessary for substantial executive rehabilitation. Consequently, these findings suggest that the BAPNE method may function as a complementary clinical adjuvant rather than a replacement for physical education.

With respect to clinical significance, the 63% remission rate observed in the BAPNE group represents a noteworthy improvement for these adolescents. Given the high prevalence of ADHD and the associated risks of social maladjustment and academic failure (5, 6), a reduction in symptom severity of this magnitude has implications for long-term developmental trajectories. Students who transition from clinically elevated inhibitory deficits to normative ranges may experience improved capacity for sustained classroom attention, more adaptive peer interactions and reduced likelihood of academic underperformance, all of which are documented correlates of executive function improvement in school-age populations (27, 28).

Furthermore, the study's situation in the Cartago province of Costa Rica provides a useful framework for educational policy in Latin America. The BAPNE method is a cost-effective intervention that requires no specialized equipment or expensive technology, making it viable for public school systems with limited resources. By integrating neuromotricity into the standard curriculum, educational authorities could potentially complement pharmacological management and address limitations of medication in treating motor deficits (7, 18).

## Conclusion

The findings of this randomized controlled trial provide an empirical foundation for the integration of neuromotricity, specifically the BAPNE method, as a non-pharmacological intervention for adolescents with ADHD. The longitudinal data, gathered over an eight-month period from a cohort of 475 students in Costa Rica, demonstrate that the systematic application of dual-task paradigms can yield significant improvements in executive dysfunction and motor coordination deficits in this clinical population.

Central to the significance of these results is the highly significant Time x Group interaction observed for the Global Executive Composite, which accounts for 26.4% of the variance in executive improvement. This finding suggests that the neuroplastic adaptations required to ameliorate executive deficits are driven by the nature of the cognitive-motor interference inherent in the BAPNE protocol. The superiority of the BAPNE method is particularly evident in its impact on core inhibitory control and cognitive flexibility, as evidenced by large effect sizes on the BRIEF-2 scales. The recorded remission rate of 63% for students with severe inhibitory deficits underscores the clinical relevance of this intervention compared to the marginal gains observed in choreographic or traditional musical education.

These results support the dual-task superiority hypothesis, which posits that the simultaneous demand for motor dissociation, rhythmic accuracy and verbal processing effectively engages the hypoactive prefrontal-striatal networks characterristic of the ADHD brain. The empirical distinction between the exercise hypothesis and the cognitive load hypothesis further clarifies that metabolic conditioning and neuromotor connectivity represent distinct training domains with differential effects on executive functioning. The high correlation between Bilateral Coordination gains and Inhibitory Control reinforces contemporary neuroscience perspectives on the motor-cognitive interface.

Several limitations of this study should be acknowledged. First, the reliance on teacher and parent ratings (BRIEF-2) introduces potential observer bias; future studies should complement informant-report measures with performance-based executive function tasks. Second, participants were not formally screened or stratified for DCD using a standardized instrument (e.g., the Movement Assessment Battery for Children), which limits the interpretation of motor improvements. Third, no follow-up assessments were conducted beyond the eight-month intervention period; longitudinal studies tracking participants into mid-adolescence are necessary to assess the durability of gains. Fourth, no neurophysiological measures (e.g., fMRI, EEG, or cortisol assays) were collected, which would provide direct evidence of the neural mechanisms underlying the observed improvements. Fifth, the non-equivalent composition of interventions across cognitive load, physical intensity, rhythmic complexity and social interaction limits attribution to any single component; dismantling designs could isolate relative contributions. Sixth, the study was conducted in a specific cultural and educational context (Cartago, Costa Rica) and generalizability to other settings remains to be established. Finally, medication status was controlled as a covariate but no medication-free subgroup analysis was performed, which would be informative for understanding pharmacological and non-pharmacological interaction effects.

Future research should address these limitations by incorporating long-term follow-up assessments, neurophysiological outcome measures, formal DCD screening and replication across diverse cultural contexts to strengthen the generalizability and mechanistic understanding of these findings.

## Abbreviations

ADHD: Attention Deficit Hyperactivity Disorder BAPNE: Body percussion, Auditory stimulation, Psychomotricity, Neuroscience, Ethnomusicology BRIEF-2: Behavior Rating Inventory of Executive Function, Second Edition BOT-2: Bruininks-Oseretsky Test of Motor Proficiency, Second Edition EF: Executive Function GEC: Global Executive Composite PFC: Prefrontal Cortex DLPFC: Dorsolateral Prefrontal Cortex RCT: Randomized Controlled Trial DCD: Developmental Coordination Disorder.

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## Author Contributions

Francisco Javier Romero-Naranjo: Conceptualization, Investigation, Methodology, Data Analysis, Interpretation, Manuscript Preparation, Software Utilization, Supervision, Validation, Literature Review, Critical Revision, Viviana Raquel Navarro-Camacho: Conceptualization, Investigation, Methodology, Practical Implementation of the Intervention with Students, Administrative

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## 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. The work has not been released as a preprint. The authors declare no actual or potential conflicts of interest in relation to this study.

## Data Availability

The datasets generated and analyzed during the current study are available from the correspondding author upon reasonable request, subject to applicable data protection and privacy regulations.

## Declaration of Artificial Intelligence (AI) Assistance

The authors declare that generative AI and AI-assisted tools were employed to aid in the refinement of language, structure and grammar during the preparation of this manuscript. However, all content, ideas, data analysis and academic interpretations presented in this work remain the result of the authors' own intellectual effort and original thought. The authors reviewed and edited all AI-assisted output and take full responsibility for the content of this publication.

## Ethics Approval

The study adhered to ethical research standards, with the research protocol approved by the board of directors of the educational institutions where data were collected. Conforming to rigorous ethical research guidelines, the study's protocol obtained formal approval from the governing boards of the participating educational institutions. Furthermore, all participants were thoroughly briefed regarding the research objectives, experimental procedures and the entirely voluntary nature of their involvement. Student identities were anonymized to ensure confidentiality. All data were securely stored and strict confidentiality and anonymity were maintained to protect participants' privacy throughout the research process.

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