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Directional Reversal Locomotor Training: Effects on Executive Function and Dynamic Balance in Children Aged 6–7 Years

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ABSTRACT

Cognitively enhanced physical activity may contribute to improving executive functions in children; however, the specificity of motor-cognitive adaptations across different domains remains unclear. This study examines the impact of a Directional Reversal Locomotor Training (DRLT) program on executive functions and dynamic balance in early school-aged children.In a randomized controlled trial, 64 first-grade children (ages 6–7 years) were allocated to either the DRLT group (n = 32) or a control group receiving regular physical education classes (n = 32) for 8 weeks. Executive functions were assessed using the Head–Toes–Knees–Shoulders Revised (HTKS-R) test, and dynamic balance was assessed using the Y-Balance Test – Lower Quarter (YBT-LQ). Post-intervention outcomes were analyzed using Analysis of Covariance (ANCOVA) with baseline scores as covariates. The DRLT program produced a significant improvement in executive functions ($p < 0.001$; Cohen's $d = 2.04$; partial $\eta^2 = 0.931$), while no significant effect was observed in dynamic balance ($p = 0.864$; $d = 0.13$). The findings support the domain-specific nature of motor-cognitive adaptations in school-based interventions and indicate that cognitively enriched locomotor training is a viable strategy for enhancing executive control in physical education settings.

Keywords: Inhibitory Control; School Intervention; Motor-Cognitive Integration; Dynamic Postural Control; HTKS-R Test; YBT-LQ Test

ABSTRAK

Aktivitas fisik yang diperkaya secara kognitif berpotensi meningkatkan fungsi eksekutif pada anak-anak; namun demikian, kekhususan adaptasi motorik-kognitif di berbagai domain masih belum sepenuhnya dipahami. Penelitian ini bertujuan mengkaji pengaruh program Directional Reversal Locomotor Training (DRLT) terhadap fungsi eksekutif dan keseimbangan dinamis pada anak usia sekolah dasar awal. Dalam uji coba acak terkontrol, 64 anak kelas satu (usia 6–7 tahun) dialokasikan ke kelompok DRLT (n = 32) atau kelompok kontrol yang mengikuti kelas pendidikan jasmani reguler (n = 32) selama 8 minggu. Fungsi eksekutif diukur menggunakan tes Head–Toes–Knees–Shoulders Revised (HTKS-R), sementara keseimbangan dinamis diukur menggunakan Y-Balance Test – Lower Quarter (YBT-LQ). Hasil paska intervensi dianalisis menggunakan Analysis of Covariance (ANCOVA) dengan skor awal sebagai kovariat. Program DRLT menghasilkan peningkatan signifikan pada fungsi eksekutif ($p < 0{,}001$; Cohen's $d = 2{,}04$; partial $\eta^2 = 0{,}931$), sementara tidak ditemukan efek signifikan terhadap keseimbangan dinamis ($p = 0{,}864$; $d = 0{,}13$). Temuan ini mendukung sifat domain-spesifik dari adaptasi motorik-kognitif dalam intervensi berbasis sekolah, dan mengindikasikan bahwa pelatihan gerak yang diperkaya secara kognitif merupakan strategi yang layak untuk meningkatkan kontrol eksekutif dalam pembelajaran pendidikan jasmani.

Kata Kunci: Kontrol Inhibisi; Intervensi Sekolah; Integrasi Motorik-Kognitif; Kontrol Postural Dinamis; Tes HTKS-R; Tes YBT-LQ

INTRODUCTION

Executive functions (EF) - including the inhibitory control, working memory and cognitive flexibility - are deemed fundamental to children's learning in the classroom and self-regulation and this makes enhancing it a priority in school-based interventions. Over the previous decade, a more researching has emerged that confirms that cognitively-engaged physical activity (i.e., movement, which involves rule-based decision making, response inhibition and rule switching) can produce reliable, though often small to moderate, in executive function for children and adolescents, with varying effect depending on the intervention design characteristics such as duration, frequency and session period (Mao et al., 2024; Song et al., 2022).

It was confirmed by the Recent quantitative analyses that physical exercise interventions might enhance the subfields of executive function for children. However, the magnitude of improvement will vary depending on the exercise pattern and the degree of cognitive load embedded within the activity (Liu et al., 2020; Wang et al., 2024). Interventions, which integrate movement with structured decision-making, rule-based responses and response inhibition demonstrate stronger executive gains compared to activity formats that are dominated by aerobic repetition or characterized by low cognitive demand (Egger et al., 2019; Mazzoli et al., 2021). These results suggest that the degree to which executive control processes are utilized and improved during movement depends on the qualitative structure of the task, rather than the physical intensity. So, motor patterns that consistently need response inhibition and rule switching in real-time in dynamic situations might offer a useful framework to improve the executive functions in the school environment.

The theoretical basis for motor interventions that are enhanced by knowledge rests on the embodied cognition frameworks that presuppose that higher cognitive processes are shaped dynamically by sensory-motor experience and by coupling of action and perception. Instead of considering the executive control processes as isolated mental operations, they are viewed as strengthened when engaging repeatedly within goal-directed motor contexts that need adaptive coordination where specific environmental constraints exist (Barsalou, 2008; Koziol et al., 2012). Moreover, neurodevelopmental explanations show that the frontal–cerebellar and frontoparietal networks, associated with executive functions, may be accomplished in a simultaneous way throughout the complex movements that entail timing, sequencing and response inhibition, which provides a potential neural basis for the transfer of motor-cognitive impacts during childhood (Diamond, 2013; Koziol et al., 2011). Starting from this perspective, motor patterns that systematically integrate response inhibition and adjustments that are based on rules may stand for a coherent theoretical path for enhancing the executive functions within real-time school settings that are ecologically valid.

Despite the enormous amount of school-based researching that supports the executive benefits of cognitively engaged physical activity, the most current interventions involve the cognitive challenges as supporting elements in the games or the educational activities, rather than building the motor structure of the task itself on a systematic principle, depending on the inhibition of motor response and reversal of rules. In several programs, cognitive engagement is added to the activity formats whose basic requirements remain aerobic or coordinative, making it challenging to isolate the contribution of repeated response inhibition under dynamic motor constraints. Furthermore, a relatively limited number of controlled experiments have simultaneously examined whether these motor-cognitive formats produce distinct adaptations across the domains of executive control and postural control (balance). This distinction is theoretically important, as task-related adaptation models suggest that improvement in one functional domain does not automatically transfer to other motor systems unless those systems are directly and progressively targeted within the training context (Paillard, 2023). Accordingly, there is a need for carefully designed school interventions in which directional reversal and rule-based motor response inhibition form the organizing principle of the motor task, with simultaneous assessment of executive function outcomes and dynamic equilibrium, to clarify the specificity and scope of training effects across different domains.

From all that has been mentioned above, the current study aims at investigating the impact of a school-based training program that is pivoted on directional reversal locomotor training (DRLT) on the executive functions and dynamic balance for children in the early stage. The intervention was designed to integrate, systematically, the reversal of rules and response inhibition into continuous motor sequences, to embody the concept of cognitively enhanced movement, considering it as the organizing principle of the task structure, rather than just a complement that was added. Two main hypotheses were formulated, which are:

The children who participate in the DRLT program are going to show more improvement and statistically significant differences in executive functions, as measured by the Head–Toes–Knees–Shoulders Revised (HTKS-R) test, compared to children who receive regular physical education classes. The second hypothesis is that the intervention did not include specific progressive loading for balance or training for instability, it is hypothesized that improvement in dynamic balance - as measured by the Y-Balance Test–Lower Quarter (YBT-LQ) - would be limited or statistically insignificant between the two groups. This design, however, allowed to test the specificity of motor-cognitive adaptations through different domains within a realistic school context with high ecological validity.

METHOD

Study Design

This study employed a randomized controlled design to investigate the effect of directional reversal locomotor training (DRLT) on executive functions and dynamic balance in first-grade primary school children (ages 6–7 years). The study was conducted during the first semester of the 2025–2026 academic year in a naturalistic school setting. The sampling frame consisted of 269 first-grade students enrolled across five private primary schools representing the total number of private schools registered in the Samarra Directorate of Education. One school was randomly selected via a documented lottery procedure conducted by an independent individual prior to obtaining any demographic or academic information. Within the selected school, two pre-existing first-grade classes (n = 72 eligible students) were included. One class was assigned to the experimental group and the other to the control group using a second documented lottery, also conducted by an independent person prior to the pretest. Classroom-level allocation was used to minimize intervention contamination between participants and to maintain procedural consistency within the educational setting.

Participants

Inclusion criteria required official first-grade enrolment (ages 6–7 years), regular school attendance, medical clearance for participation in normal physical activity, and written informed parental/guardian consent accompanied by verbal child assent. Exclusion criteria included previous diagnosis of neurological or musculoskeletal conditions affecting balance or movement, lower-limb injury within the preceding three months, medically imposed physical activity restrictions, and behavioral or cognitive difficulties interfering with testing.

Of 72 eligible students, eight were excluded due to repeated absences or failure to complete post-testing (n = 3), parental withdrawal (n = 1), exclusion from the HTKS-R test based on standard cut-off criteria (n = 1), transfer to another school (n = 1), and temporary injury or medical restriction (n = 2). The final analytic sample comprised 64 children (32 per group). The control group included 17 girls and 15 boys; the experimental group included 16 girls and 16 boys. Per-protocol analysis required attendance at a minimum of 75% of intervention sessions (at least 12 of 16 sessions).

Blinding and Contamination Control

Assessors administering the HTKS-R and YBT-LQ tests were blinded to group allocation throughout pre- and post-testing. Tests were conducted in a separate location and participant identification codes replaced any group-identifiable information. To minimize experimental contamination, DRLT sessions were held at separate times and locations from regular physical education classes. School staff were instructed not to conduct activities based on counter-conditioning principles or to share any intervention components with the control class during the study period.

Intervention

The experimental group participated in an eight-week DRLT program comprising two sessions per week (Mondays and Wednesdays), totalling 16 sessions of 40 minutes each. Training was conducted in a designated indoor physical activity space within the school.

Each session followed a consistent structure: 8–10 minutes of dynamic warm-up (light jogging, flexibility exercises, and motor coordination tasks); approximately 25 minutes of structured DRLT tasks; and 5–7 minutes of low-intensity cool-down activities.

The motor skills platform measured approximately 50 m^2 (10 × 5 metres) and was elevated 30 cm, coated with shock-absorbing foam. It incorporated sequential balance and motor skills stations arranged as a continuous circuit. A recessed obstacle (20 cm deep, 50 cm wide) with sloping sides was included, and circular markers (30 cm diameter) were positioned on both sides to facilitate controlled landings and double-sided jumps. One station featured a bifurcation point requiring a choice between two lateral paths.

The defining feature of the protocol was the directional reversal rule: directional arrows at each station indicated either horizontal (right/left) or vertical (up/down) movements, and participants were required to execute the opposite direction. For example, an upward arrow required stepping into the recessed obstacle, whereas a downward arrow required jumping over it. This rule was applied consistently across all stations, including the return leg, where arrow directions differed from the outward leg to increase cognitive flexibility demands.

Participants completed approximately 6–8 full circuit cycles per session, with standardized rest intervals of 30–45 seconds. Progressive overload was introduced across weeks through increased stimulus frequency, reduced available response time, increased course complexity, and additional directional conflicts. The protocol engaged inhibitory control (inhibition of automatic spatial responses) and cognitive flexibility (rule switching under conflicting stimuli) simultaneously, while maintaining functional balance and motor control requirements.

Intervention fidelity was ensured through session-specific checklists, attendance logs, and random monitoring by the principal researcher. During the same period, the control group followed the standard first-grade physical education curriculum (two 40-minute sessions per week), including general warm-up exercises, basic motor skills practice, and age-appropriate games, without any directional reversal rules, inhibitory response tasks, or organized directional conflicts. The same physical education teacher taught both classes in separate sessions to control for teacher-related variability.

Measures

Two outcome domains were assessed: executive functions and dynamic balance. All measurements were collected during the week preceding the intervention (pretest) and during the week immediately following the last session (posttest), at consistent times of day to minimize the influence of circadian variation or fatigue. Assessors were blinded to group allocation during both pre- and post-testing.

Executive Function: Head–Toes–Knees–Shoulders Revised (HTKS-R)

Executive functions were assessed using the test of Head -Toes – Knees - Shoulders Revised (HTKS-R), which is a validated behavioral measure of self-regulation that combines inhibitory control, working memory and cognitive flexibility (Gonzales et al., 2021; McClelland et al., 2021).

The HTKS-R test consists of four parts (parts 0 - 3) with an increasing level of complexity of the rules. Children (students) are asked to perform the opposite action of the verbal command (for instance, touching their toes when they hear the command to touch their head). With the progress throughout the different parts, the requirements for switching rules and retaining information in the working memory gradually increase.

The HTKS-R test has previously been examined and verified in terms of its psychometric properties in the Iraqi educational context and it showed fairly acceptable levels of stability and construct validity in similar age groups, which supports its cultural appropriateness and applicability to the current sample (Ibrahim et al., 2025).

All the responses were registered in accordance with an assessment system with three points: (0 = incorrect response, 1 = self-corrected response, 2 = correct response). The aggregate possible score ranged from 0 to 118 points, and the higher scores indicated a better performance in the executive functions.

The tests were conducted by trained assessors, who are not involved in the intervention, on an individual level in a quiet room. The raters passed through a formal standardized training supervised by a certified trainer who is officially authorized to administer and score the HTKS-R, to ensure the adherence to procedural protocol and to ensure the accuracy of scoring. The internal consistency coefficient in the sample was of an acceptable level (Cronbach's alpha = 0.84).

Dynamic Balance: Y-Balance Test – Lower Quarter (YBT-LQ)

The dynamic balance was assessed by using the tape-based version of the Y-Balance Test – Lower Quarter (YBT-LQ), based on the standard procedures that was described by (Gribble et al., 2012) and supported by (Brumitt et al., 2019). Participants were tested barefoot, maintaining single-leg stance while extending the free foot in three directions: anterior (ANT), posteromedial (PM), and posterolateral (PL). Two practice trials per direction were performed before three recorded test attempts. Maximum reach distances (cm) were recorded for each direction on each limb.

Lower limb length was measured in the supine position from the anterior superior iliac spine (ASIS) to the distal medial malleolus. The composite score for each limb was calculated as: Composite Score (%) = [(ANT + PM + PL) ÷ (3 × limb length)] × 100. The final YBT-LQ score was computed as the mean of right and left composite scores to reduce the influence of lateral dominance. Attempts were invalidated if the participant lifted the supporting foot, failed to return to the starting position in a controlled manner, transferred weight to the reaching foot, or lost balance before task completion. Test-retest reliability on a subsample of 14 students demonstrated excellent intraclass correlation (ICC = 0.94).

Statistical Analysis

E5A priori power analysis using G*Power (version 3.1) indicated that a total sample of 64 participants (32 per group) was sufficient to detect a medium group difference (Cohen’s d = 0.50) with 80% statistical power at a two-tailed significance level of $\alpha = 0.05$ (Lakens, 2013). All analyses were performed using IBM SPSS Statistics (version 26) on a per-protocol basis, including only participants who attended ≥75% of sessions and completed both testing occasions.

Descriptive statistics (mean ± SD) were calculated for all continuous variables. Baseline group equivalence was examined using independent-samples t-tests for continuous variables and chi-square tests for categorical variables. Primary intervention effects were analyzed using one-way ANCOVA, with post-test scores as dependent variables, group as the fixed factor, and corresponding pre-test scores as covariates. ANCOVA assumptions were verified by Shapiro-Wilk test (normality of residuals), Levene's test (variance homogeneity), and examination of group × baseline interaction (homogeneity of regression slopes). Outliers were examined using boxplots and standardized residuals (±3.29). Effect sizes were reported as Cohen's d (group difference) and partial η^2 (ANCOVA), with 95% confidence intervals. Statistical significance was set at $p < 0.05$ (two-tailed).

Ethical Considerations

The study was conducted in accordance with the Declaration of Helsinki and received approval from the Scientific Research Ethics Committee at the University of Samarra (Approval No. 17, dated 2 June 2025). Written informed consent was obtained from parents or guardians, and verbal assent was obtained from all participating children. Participation was voluntary, data confidentiality was maintained through identification codes, and no intervention-related adverse events were recorded.

RESEARCH RESULTS

Participant Flow and Baseline Characteristics

A total of 64 children were included in the final per-protocol analysis, with 32 participants in each group. No missing data were recorded for baseline characteristics or outcome variables. Independent-samples t-tests and chi-square analyses revealed no statistically significant differences between the control and DRLT groups in age, height, weight, sex distribution, HTKS-R pre-test scores, or YBT-LQ composite pre-test scores (all p > 0.050), confirming acceptable baseline comparability (Table 1).

Table 1. Baseline Characteristics of Participants by Group

Variable	Control (n = 32)	DRLT (n = 32)	P-value
Age (years)	6.35 ± 0.17	6.27 ± 0.19	0.091
Height (cm)	118.54 ± 3.19	119.54 ± 3.36	0.229
Weight (kg)	23.66 ± 2.44	23.63 ± 2.67	0.953
Sex (Boys/Girls), n	15 / 17	16 / 16	1.000
HTKS-R (Pre)	52.89 ± 3.68	53.22 ± 3.88	0.732
YBT Composite (%) (Pre)	79.38 ± 3.34	79.16 ± 3.19	0.790

Values are presented as mean ± SD. HTKS-R = Head-Toes-Knees-Shoulders Revised; YBT = Y-Balance Test. Statistical significance set at p < 0.050.

Pre–Post Descriptive Outcomes

The DRLT group demonstrated a marked increase in mean HTKS-R scores from pre- to post-measurement (53.22 ± 3.88 to 61.94 ± 4.17), whereas the control group showed minimal change (52.89 ± 3.68 to 54.06 ± 3.52). In contrast, YBT-LQ composite scores showed only minor changes in both groups, with no meaningful descriptive difference between groups. Full descriptive statistics are presented in Table 2.

Table 2. Descriptive Statistics for HTKS-R and YBT-LQ Scores Before and After Intervention

Outcome	Time	Control (n = 32)	DRLT (n = 32)
HTKS-R	Pre	52.89 ± 3.68	53.22 ± 3.88
	Post	54.06 ± 3.52	61.94 ± 4.17
YBT Composite (%)	Pre	79.38 ± 3.34	79.16 ± 3.19
	Post	79.94 ± 3.41	80.38 ± 3.26

Values are presented as mean ± SD. HTKS-R = Head-Toes-Knees-Shoulders Revised; YBT = Y-Balance Test – Lower Quarter.

Intervention Effects: ANCOVA Results

Separate one-way ANCOVAs were conducted for each outcome variable, with post-test scores as dependent variables, group as the fixed factor, and corresponding pre-test scores as covariates. After adjusting for baseline performance, a statistically significant group effect was found for HTKS-R scores, F (1, 61) = 819.979, $p < 0.001$, partial $\eta^2 = 0.931$, indicating a large effect of the DRLT intervention on executive functions. The between-group effect size was large (Cohen's d = 2.04, 95% CI [1.33, 2.74]).

In contrast, no statistically significant group effect was observed for YBT-LQ composite scores, F(1, 61) = 0.030, p = 0.864, partial $\eta^2 = 0.001$, indicating no significant intervention effect on dynamic balance after adjusting for pre-test values. The corresponding effect size was small (Cohen's d = 0.13, 95% CI [−0.36, 0.62]). Complete ANCOVA results are presented in Table 3.

Table 3. ANCOVA Results for Post-Intervention Outcomes Adjusted for Baseline Values

Outcome	F (1, 61)	p-value	Partial η^2
HTKS-R (Executive Function)	819.979	0.000	0.931
YBT Composite (%) (Dynamic Balance)	0.030	0.864	0.001

Baseline value of each outcome was entered as a covariate. Statistical significance set at $p < 0.050$.

DISCUSSION

This randomized controlled experiment, which was conducted by means of using two first-grade classes in a randomly selected primary school, examined the effect of directional reversal learning training (DRLT) on executive functions and dynamic balance in early school-aged children. The results showed a significant improvement in executive functions as measured by the HTKS-R test, while no statistically significant differences were found between the two groups in dynamic balance (YBT-LQ).

Since the DRLT program includes frequent demands for response inhibition, rule switching and quick movement command updates, which are all essential elements for the executive control system, this disparity is thought to be consistent from a theoretical point of view. However, dynamic equilibrium adaptations depend frequently on the targeted and specific postural constraints in addition to specific neuromuscular loading, which targets postural control systems - elements that were not specifically included in the current design of intervention. These results agree with the empirical data and this indicates that, compared to other motor domains when not directly trained, motor interventions that deliberately include cognitive challenges typically lead to stronger and more consistent gains in the executive functions (Crova et al., 2014). The current results are also consistent with the recent meta-analytic findings that cognitively enriched physical activity has vital effects on childhood executive control processes (Mao et al., 2024).

The prominent improvement in HTKS-R performance can be explained after the DRLT program considering the intensive cognitive structure, which characterizes the intervention. On the contrary of the traditional motor activities, DRLT requires children to inhibit automatic spatial responses, maintain and update rule representations and switch flexibly between the competing directional commands within specific time constraints. These needs match the executive components measured by the HTKS-R test, especially response inhibition and cognitive flexibility.

From the perspective of task particularity, repeated engagement in these control processes of higher order enhanced the executive performance through targeted and specific cognitive activation. Empirical results show that physical activity programs, which involve structured cognitive engagement could achieve greater improvements in executive functions in comparison to activities, which lack explicit cognitive demands (Schmidt et al., 2016). Contemporary research on cognitively enriched physical activity also confirms that the qualitative integration of cognitive and motor demands is a critical component in achieving benefits related to executive control (Mavilidi et al., 2023).

Theoretical propositions also suggest that developing the executive function becomes the most effective when interventions target response inhibition, working memory and cognitive flexibility simultaneously within meaningful task contexts (Diamond & Ling, 2016). Therefore, the close alignment between the cognitive structure of the DRLT program and the executive requirements of the HTKS-R test provides a logical, task-specific explanation for the improvement observed.

The size of the effect between the two groups observed in the HTKS-R test calls for careful analytical interpretation. One possible explanation is the degree of process overlap between the executive requirements that were repeatedly activated within the DRLT program and those measured by the HTKS-R test. Contemporary literature in the field of cognitive training suggests that transfer effects are more likely when the training task and the measurement task rely on highly shared cognitive mechanisms, particularly within the framework of near transfer (Pahor et al., 2022).

So, in this context, the repeated activation of behavioral inhibition processes and the transformation of rules embedded in the DRLT protocol contributed to the enhancement of executive control processes directly compatible with the requirements of the HTKS-R test. Therefore, the noticeable improvement in the performance of the experimental group appears to be consistent with a task-specific reinforcement mechanism, rather than an indicator of general interdomain cognitive improvement.

In contrast to the results for executive functions, directional reversal learning training (DRLT) did not show a statistically significant improvement in dynamic balance (YBT-LQ), a pattern consistent with the principle of training specificity. Contemporary theories of balance training emphasize that postural adaptations are largely task-specific and reflect the cumulative effects of specific postural tasks that are repeatedly trained, rather than broad transfer to untrained balance contexts (Paillard, 2023).

Even though DRLT involved coordinated transitional movements, obstacles overcome and rapid directional reversals and its requirements of balance were maintained in a deliberate way at the functional level to ensure smooth movement, responsiveness and rapid switching of rule. Consequently, the protocol might lack elements of progressive instability, sustained stabilization phases and structured loading on balance that are necessary components of measurable neuromuscular adaptations.

The evidence, which are derived from the sport contexts enhance this interpretation, as a study of high-level badminton players demonstrated that improvements in dynamic balance and agility are higher when specific balance training in unstable conditions was combined with plyometric training (Lu et al., 2022). Totally, these results imply that DRLT may contribute to maintain the baseline balance but also achieve important improvement in YBT test scores and it likely require adding guided balance tasks that are progressively challenging that match the postural control demands measured by the test.

The discrepancy noticed between the improved executive functions and the absence of measurable gains in dynamic equilibrium highlights the domain-specific nature of motor-cognitive adaptations in the stage of childhood. Although executive functions and postural control may interact during complex motor performance, accumulating evidence suggests that improvements in executive functions are more pronounced when physical activity explicitly involves cognitively demanding requirements, such as grasping, switching rules, and flexibly selecting responses (1abcde et al., n.d.; Vazou et al., 2019).

On the other hand, the dynamic balance adaptations tend to rely more heavily on repeated exposure to task-specific postural challenges that closely mimic the context of the measurement instrument used (Gribble et al., 2012). Under the current protocol, DRLT systematically imposed rapid directional reflections and rule-based dexterous control; however, its balance requirements were deliberately maintained at a functional level to preserve fluidity of movement and cognitive engagement, rather than to induce progressively increasing situational load.

It is likely that this selective training focus explains the reason behind achieving significant gains in executive performance, while dynamic balance—as measured by the YBT-LQ test—remained largely unchanged. These findings are consistent with theoretical propositions and meta-analytic evidence suggesting that qualitatively enriched physical activity preferentially enhances the cognitive processes that are directly trained, while improvements in other distinct motor domains remain unlikely unless those domains are explicitly and progressively targeted within the intervention design (Mavilidi et al., 2023; Pesce, 2012).

In addition to that - from a neurocognitive perspective - the gains in executive functions that were observed after the DRLT can be explained by the repeated and simultaneous activation of frontal and motor networks during cognitively demanding movements. The contemporary models of the embodied cognition suppose that motor and executive processes are interconnected functionally rather than independent, because the coordinated movement within the constrains that are based on rule constraints engages fronto-striatal and fronto-parietal circuits circles that are involved in cognitive control and perceptual flexibility (Koziol et al., 2012).

In particular, the tasks, which need a rapid directional reversal according to the rules imposed externally probably activate the dorsolateral prefrontal cortex (DLPFC) and supplementary motor domains, two structures, which are essential for response inhibition and action reprogramming. The repeated activation of these networks during the DRLT might have enhanced neural efficiency within executive control systems, and this leads to performance improvement in the HTKS-R test.

It is worth noting that such neural adaptations are more likely to occur when cognitive requirements are integrated directly into the execution of the movement, rather than presented separately; integrated motor-cognitive interaction appears to enhance the engagement of the anterior frontal cortex compared to purely aerobic activity (de Greeff et al., 2018). This mechanistic explanation provides a plausible biological framework for the marked improvement in executive functions observed in the experimental group. Overall, the current findings provide evidence that rule-based, counter-directional motor training can significantly enhance executive function performance in children in the early school years, when cognitive flexibility and rapid perceptual flexibility are systematically integrated into motor tasks.

The absence of parallel improvement in dynamic balance also illustrates that motor-cognitive adaptations are not distributed evenly across different domains but rather reflect the specific motor-cognitive constraints and demands imposed by the intervention design. It is worth mentioning that such neural adaptations are more likely to occur when cognitive requirements are directly integrated into the execution of the movement, rather than presented separately; integrated motor-cognitive interaction appears to enhance the engagement of the anterior frontal cortex compared to purely aerobic activity (de Greeff et al., 2018). This mechanistic explanation provides a plausible biological framework for the marked improvement in executive functions observed in the experimental group.

Overall, the current findings provide evidence that rule-based, counter-directional motor training can significantly enhance executive function performance in children in the early school years, when cognitive flexibility and rapid perceptual flexibility are systematically integrated into motor tasks. The absence of parallel improvement in dynamic balance also illustrates that motor-cognitive adaptations are not distributed evenly across different domains but rather reflect the specific motor-cognitive constraints and demands imposed by the intervention design.

When integrating structured cognitive challenges into the functional motor activities that were carried out in a natural school setting, DRLT appears to provide a practical and ecologically valid method for enhancing the executive control during a sensitive developmental period. These findings contribute to enrich an increasing amount of literature that refer that the qualitative design of physical activity, not just the amount of activity, plays a vital role in shaping the cognitive outcomes in the stage of childhood.

Limitations and Future Research

This study includes several limitations that should be considered when interpreting the results. Although the participating schools were randomly selected from a pool of eligible schools, conducting the experiment within a single educational context may limit the generalizability of the results to other educational settings. In addition to that, the use of per-protocol analysis could impact the effect size estimates and so, future studies ought to include intention-to-treat analyses. In addition, the absence of neurophysiological measurements prevents direct inference about the neural mechanisms underlying the observed improvement. Therefore, it is recommended that the study be replicated across multiple schools, along with exploring hybrid protocols that combine cognitively enriching directional reflection with gradual qualitative loading on balance.

Practical Implications

The results indicate that the executive functions can be enhanced within physical education classes by integrating cognitive demands and rule changes directly into transitional motor activities, without the need to additional time or special equipment. However, improving the dynamic balance is likely to require the inclusion of tasks, which are graded in terms of challenge and carefully designed to match the requirements of the measurement tool used.

CONCLUSIONS AND RECOMMENDATIONS

The latest directional reversal-based movement training (DRLT) has produced significant improvements in executive functions in children in their early school years, while dynamic balance performance stayed stable with little change. This difference enhances the nature of motor-cognitive adaptations and confirms the need to align intervention constraints and design with targeted functional outcomes. Through the systematic integration of rule switching and behavioral demands within structured transitional motor tasks, DRLT shows that the enriching the movement cognitively is a practical and ecologically sound strategy for enhancing executive processes in the school lessons of physical education. More research should scrutiny if the integration of specifically targeted progressive loading for balance within such cognitively intensive protocols can participate in boarder adaptations across various domains without affecting the executive gains achieved negatively.

The latest directional reversal-based movement training (DRLT) led to significant improvements in the executive functions for children in early school years. On the other hand, dynamic balance performance has remained stable with a slight change only. This difference supports the nature of motor-cognitive adaptations and highlights the requirement to align intervention constraints and design with the targeted functional outcomes. Through the systematic integration of behavioral demands and rule switching within structured transitional motor tasks, DRLT shows that the movement enriched cognitively can be a practical and an ecologically grounded strategy for enhancing executive processes in the lessons of physical education at school. Future research should investigate whether the integration of specifically targeted progressive loading for balance within such cognitively intensive protocols can contribute to broader interdomain adaptations without weakening the executive gains achieved.

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