ORIGINAL ARTICLE

Stroop-based locomotor training improves executive attention and running in preschoolers

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Abstract

Background and Study Aim Motor training programs that integrate cognitive demands are increasingly used in early childhood education. Approaches based on the Stroop principle combine motor actions with inhibitory control and attentional regulation, which are closely related to executive attention and basic motor skills in preschool children. Despite the application of various cognitively enriched motor tasks, their relative effectiveness in improving executive attention and locomotor performance remains a matter of practical interest. This study investigates the impact of a motor training program derived from the principle of reflection in the Stroop task on executive attention, running, and jumping skills in preschool children.

Material and Methods A randomized experiment was conducted in two kindergartens. A total of 72 children aged 5–6 years participated and were divided into two groups: experimental and control. The intervention lasted eight weeks with four sessions per week. Children in the experimental group performed running and jumping tasks based on the Stroop principle. Their executive attention was measured using the Day–Night Stroop task. Motor performance was assessed using standardized running and jumping tests. Data normality was verified, and analysis of covariance (ANCOVA) was used to compare pre- and post-test results.

Results The experimental group showed a significant improvement in executive attention ($p < .01$) and running speed ($p < .01$). However, no significant improvement was observed in the standing long jump test ($p = .343$) compared with the control group. Effect sizes ranged from moderate to large. In contrast, the control group showed no significant changes in Stroop test performance or jump distance. A moderate improvement in running speed was observed.

Conclusions Motor training can contribute to the enhancement of executive attention and basic motor skills in preschool children. These findings are consistent with embodied cognition research and contribute to the development of innovative educational practices in early childhood.

Keywords: executive attention, stroop effect, transitional motor skills, preschool children, cognitive-motor integration.

Introduction

Executive attention and fundamental locomotor skills develop intensively during the preschool period and form an important foundation for later learning and physical activity. During this stage, children are required to coordinate cognitive control processes with movement execution in increasingly complex environments. The integration of attention, inhibition, and motor coordination plays a critical role in successful running and jumping performance, which are key components of early motor competence. At the same time, motor activities that require simultaneous cognitive engagement may place additional demands on executive control. This highlights the practical importance of understanding how such combined demands influence attention and locomotor performance in preschool children.

Executive attention, which involves inhibitory control and cognitive flexibility, represents an important aspect of cognitive development in early childhood. It allows preschool children to regulate behavior, respond adaptively to new stimuli, and prepare for academic learning [1, 2]. This developmental period coincides with the maturation of anterior frontal cortex regions, particularly the dorsolateral and anterior cingulate areas. This temporal alignment has been associated with the role of early interventions in supporting cognitive development over time [3, 4].

There is evidence supporting the role of structured motor interventions, particularly those that include challenges related to transitional skills and balance, in the consolidation of executive

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functions in preschool children. For instance, Hao et al. [5] reported significant improvements in working memory following a twelve-week motor learning program compared with free play. Similarly, structured motor protocols appear to improve physical fitness and motor efficiency, while also producing additional gains in inhibitory control [6]. Recent meta-analyses have shown small to moderate effect sizes (g = 0.15–0.44) for structured physical interventions on executive function outcomes in early childhood [7, 8].

Despite the growing interest in embodied cognitive approaches aimed at developing executive functions in early childhood, many existing interventions primarily focus on general cognitive engagement during movement. As a result, the specific interrelation between Stroop-like interference and transitional motor tasks remains insufficiently examined, limiting theoretical understanding of how executive control can be trained through movement.

From a theoretical perspective, embodied cognition theory conceptualizes motor actions and physical experiences not merely as outputs of cognitive processes, but as integral components of cognitive organization and construction [9]. Within this framework, cognitive control is shaped through continuous interaction between perception, action, and environmental demands.

Several embodied approaches emphasize the integration of cognitive conflict into motor activity, particularly through mechanisms related to response inhibition and attentional control. In such approaches, Stroop-like interference can be induced through visual-motor or auditory-motor cues, requiring children to execute movements that conflict with presented signals and thereby creating sensorimotor incongruence during movement execution.

In this respect, combining movement with cognitive challenges, such as inhibition or attentional shifting, activates integrated networks between frontal and motor cortices. This integration may support executive attention more effectively than physical activity alone [8, 10]. Recent systematic reviews indicate that cognitively enriched motor interventions outperform purely physical approaches in enhancing executive functions in preschool children [11]. In addition, well-established studies have demonstrated strong associations between gross motor proficiency and executive functions across diverse contexts, including large-scale samples from Australia and China [12, 13].

Most previous cognitive-motor interventions have relied on discrete or fixed actions, even when incorporating elements of response inhibition or rule switching. In contrast, fewer approaches have examined continuous transitional movements that require real-time integration of executive control with ongoing motor regulation.

A further theoretical and methodological limitation concerns the limited application of the classic Stroop interference model, which is regarded as a cornerstone of cognitive control research, in embodied motor training for young children. Although computerized Stroop tasks have proven effective in school-aged children [4, 14], their translation into embodied motor activities involving directional conflict has received limited attention. The integration of Stroop-like interference, such as incongruent instructions for running or jumping, may therefore represent a promising pathway for training executive attention in developmentally appropriate and physically engaging ways [15, 16].

Most existing studies emphasize object-control activities, such as throwing and catching, whereas transitional motor tasks, including running and jumping, remain underrepresented. This is related to their close association with natural play patterns and daily motor routines. Such limitations are particularly evident in low- and middle-income countries, where scalable and low-cost cognitive-motor interventions are needed to support early cognitive and motor development [17].

In the literature, increasing attention has been given to training models that integrate executive cognitive demands with transitional motor skills within play-based environments for preschool children. In this context, Stroop-based approaches have been discussed as a potential framework for combining response inhibition and cognitive flexibility with movement tasks involving directional or color-based conflict. Such approaches have been associated with changes in executive attention, particularly inhibitory control and cognitive flexibility, as well as with motor outcomes related to running, balance, and coordinated movement.

Discussions of low- and middle-income country (LMIC) contexts frequently emphasize the relevance of low-cost and equipment-free motor interventions that can be implemented within the practical constraints of early childhood education systems. These contexts are often used to examine the feasibility and ecological relevance of embodied cognitive-motor approaches in diverse educational settings.

Although physical activity-based interventions have been linked to executive function development in early childhood, existing reviews indicate that much of the available evidence originates from high-income educational contexts and displays substantial methodological variability. In addition, relatively limited attention has been paid to structured, cognitively enriched motor programs implemented across diverse preschool environments [18, 19, 20].

In this context, the aim of the study is to examine the effects of motor training based on visual–

directional interference, analogous to the Stroop principle, on executive attention and transitional motor skills in preschool children.

Materials and Methods

Participants

The study population consisted of preschool children aged 5–6 years attending five non-governmental kindergartens in Samarra, Iraq. Using random selection (lottery method), two kindergartens were selected as the study sample and randomly allocated to either the experimental or the control group. The allocation procedure was performed by an administrative employee who was independent of the intervention and outcome assessment, ensuring allocation concealment.

A total of seventy-two (72) children with typical development (M = 5.43 years, SD = 0.29) were selected and randomly assigned to two groups (experimental and control), with thirty-six (36) children in each group (18 males and 18 females per group). Inclusion criteria required that participants had achieved age-appropriate developmental milestones, had no neurological or motor impairments, and had written informed consent provided by their parents or legal guardians. Ethical approval was obtained from the University of Samarra (Approval No. 13, Date: June 30, 2025), and the study was conducted in accordance with the principles of the Declaration of Helsinki.

Study Design

The study employed a randomized experimental design with pre- and post-testing. The experimental group received an organized motor play program based on inverse signals derived from the Stroop task. The program targeted executive attention and basic motor skills in preschool children.

The intervention lasted eight (8) weeks and included twenty-four (24) training sessions, with an average of three sessions per week. Each session lasted thirty (30) minutes. The experimental group participated in an organized play program based on inverse signals derived from the Stroop task, and it involved multiple patterns of sensory input. In contrast, the control group continued the usual kindergarten activities without conflicting cognitive components, reverse rules, or challenges to execution control. The time schedule of the experimental group was matched in terms of the number and duration of sessions.

The program targeted executive attention and basic motor skills through tasks that challenged inhibitory control, cognitive flexibility, and memory. These tasks operated through visual and auditory signals that were in contradiction with the required movement. Each session included five organized activity stations.

Each training session followed a standard structure. The five activity stations were arranged within a designated indoor play area measuring 12 × 12 meters to allow safe task execution. Each station lasted approximately 5–6 minutes and included 6 to 10 repetitions per child, depending on task complexity. Visual stimuli consisted of colored cards, arrows, or geometric symbols (A4 size). Auditory stimuli were presented orally by the trainer.

Children received brief standardized instructions before each task (e.g., “move in the opposite direction of the signal”), followed by immediate task execution. The order of tasks was fixed across all sessions to ensure procedural consistency. Short transition periods of approximately 30 seconds were provided between stations.

Task difficulty was gradually increased throughout the eight-week program through systematic elevation of stimulus–response conflict, reduction of response preparation time, and integration of multiple sensory stimuli within a single task. The progression rules were applied consistently across all sessions.

The intervention was implemented by well-trained teachers in accordance with a unified standardized protocol. Informal monitoring of adherence to the session structure was conducted to ensure consistent delivery across all training sessions. Session implementation was monitored using short checklists focusing on the sequence of tasks, the method of stimulus presentation, and the level of participant interaction. This procedure ensured adherence to the intended structure of the intervention.

1. Tasks of optical-directional reflection

Children were instructed to move in the opposite direction of the visual signal. For example, an arrow pointing to the left required movement to the right. The activities included:

- Zigzag running using reverse-direction instructions.
- Sideward jumping between oppositely colored cones.

2. Tasks of contradiction between color and meaning

Responses were based on color signals with inverse meanings, for example, red indicating “go” and green indicating “stop.” The activities involved:

- Rapid running exercises following inverse traffic signals.
- Jump-freeze sequences based on conflicting color commands.

3. Tasks of symbol–action reconnection

Familiar visual symbols were associated with counterintuitive motor responses, for example, circle indicating jumping and triangle indicating running backward. The activities included:

- Exercises based on shapes with alternating responses.
- Rapid alternation activities using symbol–action

contradiction.

4. Tasks of acoustic-motor contradiction

Verbal instructions deliberately contradicted the required movements, for example, “run” indicating freezing. The activities included:

- Crossing hurdles based on inverse verbal commands.
- Running and stopping tasks conditioned by acoustic-motor contradiction.

5. Tasks integrating multisensory reflection

In the final stage, auditory and visual signals were combined to increase cognitive load. The activities included:

- Running and jumping in circles using two simultaneous signals with reverse logic.
- Multimedia inhibitory games requiring rapid switching.

Each station lasted 5–6 minutes, allowing balanced distribution of activities within the 30-minute session. Task difficulty gradually increased over the intervention period to support progressive engagement at executive and motor levels.

An operational description of the intervention at the task level is provided in the text. This includes the materials used, approximate timing, number of repetitions, spatial arrangements, and examples of visual and auditory stimuli. These elements are presented through the integrated description of session structure and station protocol outlined above. The complete detailed task-level protocol is available upon request to facilitate independent replication of the intervention.

Instrument

Assessment was conducted using the Day–Night Stroop test [18], which is a validated measure of response inhibition in early childhood. The task consisted of 16 trials administered individually in a quiet room. Responses were coded dichotomously (correct/incorrect). The total number of correct responses was used as the outcome variable for statistical analysis.

Both response accuracy (percentage of correct responses) and response time (in seconds) were recorded. Although multiple alternatives exist for assessing executive attention, the Day–Night Stroop task was selected to ensure construct validity and comparability with previous intervention studies. In this study, methodological originality did not lie in the measurement tools themselves, but in the intervention mechanism being tested. The selection of this instrument was also guided by considerations of applicability, simplicity, and suitability for resource-limited educational environments.

Motor Performance Tests

Motor performance was evaluated using selected subtests from the Test of Gross Motor Development – Second Edition (TGMD-2) [19]. The following tests were included:

- *10-meter run:* Performance was measured using a digital stopwatch. The average of two attempts was recorded and used directly in the statistical analysis.
- *Standing long jump:* The distance from the takeoff point to the nearest heel mark upon landing was measured. The best of two attempts was recorded.

All assessments, conducted before and after the intervention, were performed by trained evaluators who were blinded to group allocation. The testing environment was standardized across both study sites to ensure consistency.

The assessment procedures were conducted independently of the training sessions. The evaluator responsible for testing did not participate in the intervention, reducing the likelihood of familiarity with group allocation.

Statistical Analysis

Before conducting statistical analysis, the data were examined for missing and extreme values. No substantial missing data were identified. Statistical analyses were performed using the SPSS statistical package (version 26). The Shapiro–Wilk test was used to assess normality. Levene’s test was applied to examine the homogeneity of variances. Homogeneity of regression slopes was also checked as part of the ANCOVA assumptions. Although slight deviations from normal distribution were observed, parametric analyses were applied due to the adequate sample size and the robustness of t-tests and analysis of covariance (ANCOVA) under such conditions [20]. Descriptive statistics, including means, standard deviations, and ranges, were calculated for all variables. Paired t-tests were used to examine within-group changes. Analysis of covariance (ANCOVA) was applied to compare post-test scores between groups while controlling for baseline differences. Effect sizes were calculated to complement significance testing. Cohen’s d was used for within-group differences, and partial eta squared (η^2_p) was reported for ANCOVA effects. Statistical significance was set at $p < .05$ (two-tailed). When multiple statistical comparisons were conducted, the results were interpreted with reference to the primary study variables.

Results

The results of the statistical analyses are presented in Table 1. Descriptive statistics for executive attention, 10-meter running speed, and standing long jump performance are shown for both groups at pre- and post-testing. As shown in Table, descriptive statistics include arithmetic means, standard deviations, and ranges for pre- and post-measurements of each variable in both groups. These data provide an overview of performance changes over the intervention period.

As shown in Table 2, the Shapiro–Wilk test indicated that Stroop test scores at certain measurement points did not follow a normal distribution in both groups (p < .05). In contrast, most of the remaining variables showed normal distributions (p > .05). On this basis, parametric tests were applied, taking into account the sufficient sample size and the robustness of the t-test.

As shown in Table 3, Levene's test indicated homogeneity of variances between the experimental and control groups for all pre-test variables (p > .05).

As shown in Table 4, paired-sample t-tests indicated statistically significant improvements in the experimental group for Stroop test accuracy (t(35) = 10.90, p < .001) and 10-meter running speed (t(35) = 7.08, p < .001). No statistically significant improvement was observed in standing long jump performance (p = .343). In contrast, the control group showed no significant changes in Stroop test performance or jump distance, whereas a significant improvement in running speed was observed (p = .0002).

As shown in Table 5, effect sizes calculated using Cohen's d indicated large effects in the experimental group for Stroop test performance and 10-meter running speed. In contrast, the effect size for standing long jump distance was small. In the control group, effect sizes ranged from trivial to small across all measures.

Table 5. Cohen's d effect sizes (pre-test to post-test) by group

Table 1. Descriptive statistics by group and time (n = 36)

Variables	Group	Pre-test (Mean ± SD)	Post-test (Mean ± SD)	Min–Max (Pre-test)	Min–Max (Post-test)
Stroop (points)	Control	10.75 ± 1.18	10.94 ± 1.24	9–13	8–13
	Experimental	10.72 ± 0.94	13.31 ± 1.01	9–13	10–15
Run 10 m (s)	Control	3.90 ± 0.09	3.82 ± 0.08	3.71–4.12	3.65–3.99
	Experimental	3.85 ± 0.09	3.68 ± 0.09	3.68–4.05	3.50–3.86
Jump (cm)	Control	92.86 ± 5.39	94.40 ± 6.11	79.3–99.0	76.9–102.0
	Experimental	93.46 ± 5.06	94.78 ± 6.60	83.4–101.3	82.6–101.8

Table 2. Shapiro–Wilk normality test results

Variables	Group	Pre-test (p)	Post-test (p)
Stroop (points)	Control	0.0041	0.0233
	Experimental	0.0900	0.0200
Run 10 m (s)	Control	0.8720	0.8454
	Experimental	0.7226	0.8722
Jump (cm)	Control	0.5294	0.7757
	Experimental	0.2393	0.3231

Table 3. Levene's test for homogeneity of variances (pre-test scores)

Variables	Levene's p-value
Stroop (points)	0.2537
Run 10 m (s)	0.8521
Jump (cm)	0.8993

Table 4. Paired-sample t-test results (pre-test vs post-test within each group)

Variables	Group	Paired Sample t-Test		Interpretation
		t-value	p-value	
Stroop (points)	Control	0.879	0.3853	Not significant
	Experimental	10.902	0.001	Significant
Run 10 m (s)	Control	4.200	0.0002	Significant
	Experimental	7.077	0.001	Significant
Jump (cm)	Control	1.211	0.2339	Not significant
	Experimental	0.961	0.3429	Not significant

Variables	Group	Cohen's d
Stroop (points)	Control	0.147
	Experimental	1.817
Run 10 m (s)	Control	0.700
	Experimental	1.179
Jump (cm)	Control	0.202
	Experimental	0.160

Discussions

The aim of this study was to examine the effects of a Stroop-based locomotor training program on executive attention and basic motor performance in preschool children. The results indicate that the experimental group demonstrated significant improvements in executive attention and 10-meter running speed, whereas no significant changes were observed in standing long jump performance. In contrast, the control group showed no meaningful changes in executive attention or jumping ability, with only a moderate improvement in running speed. Overall, these findings suggest a selective effect of cognitively enriched motor training on executive attention and task-specific locomotor performance in early childhood.

The essence of the intervention rested on stimulating executive attention, particularly inhibitory control, through organized transitional motor tasks based on rules designed in accordance with the Stroop task model. Each session required children to respond to dynamic visual or auditory stimuli that contradicted instinctive responses. This process required suppression of spontaneous behaviors and activation of cognitive control mechanisms. Previous research has shown that repeated exposure to conflict-solving tasks embedded in physical play contributes to improved frontal cortex efficiency and increased neural connectivity associated with executive functions [21, 22, 23]. It is worth mentioning that the diversification and progressive increase in task complexity throughout the eight-week program were designed to maintain children's motivation while gradually increasing cognitive load, an approach supported by recent meta-analyses on executive function training in early childhood [24].

Thus, the significant gains in Stroop test accuracy observed in the experimental group can be attributed not only to task repetition, but also to the adaptive and multisensory structure of the program. This structure reflects principles of embodied and scaffolded learning.

The findings also provide evidence supporting the effectiveness of cognitively enriched motor interventions derived from the Stroop task and based on visual response reversal frameworks in enhancing executive attention and selected motor outcomes in preschool children. The experimental group demonstrated statistically significant improvements in inhibitory control, as measured by Stroop test accuracy, and in 10-meter running speed, with large effect sizes. No significant differences were observed in standing long jump performance. These findings are consistent with a growing body of experimental research suggesting that targeted motor–cognitive interventions support executive function development during early neural maturation [1, 19, 25].

The marked improvement in Stroop task performance in the experimental group aligns with studies highlighting the adaptability of executive attention when trained through embodied and play-based learning approaches [3, 26]. By integrating cognitive conflict with motor response reversal, the intervention created an environmental context that required repeated practice of inhibitory control, cognitive flexibility, and attentional shifting. These executive processes are supported by neural circuits within the frontal cortex [2]. The results are also consistent with evidence supporting the effectiveness of the HTKS-R framework in training executive functions, particularly when adapted to dynamic whole-body movement tasks that challenge dominant responses [17, 26].

The observed improvement in 10-meter running speed in the experimental group suggests interaction between cognitive control and transitional motor efficiency. Previous studies have demonstrated that incorporating executive function challenges into structured physical activity enhances neuromuscular coordination and movement efficiency [5, 8]. This relationship can be interpreted through the cognitive–energetic model, whereby regulation of arousal, attention, and effort contributes to improved motor output [27]. In addition, running tasks performed under changing rules or in response to signal-based cues may activate fronto-striatal circuits involved in both executive control and movement speed [21, 28].

In contrast, the absence of significant improvement in standing long jump performance indicates limited transfer of motor–cognitive training to tasks relying primarily on explosive strength. Jump performance depends on rapid force production, advanced neuromuscular coordination, and elastic energy utilization. These elements were not directly targeted by the program, which focused primarily on cognitive conflict rather than mechanical loading. This finding is consistent with previous evidence indicating that improvements in explosive strength require task-specific resistance-based training [29, 30].

The findings support embodied cognition theory, which conceptualizes cognitive processes as grounded in sensorimotor experiences [29]. The program operationalized this principle by requiring children to execute physical actions in response to abstract and conflicting rules, thereby linking cognitive demands with motor execution. Previous research has shown that such embodied executive function training is associated with neuroplastic changes in frontal brain regions during early childhood [23], contributing to improvements in self-regulation and academic readiness.

Overall, these findings add to the growing literature advocating the integration of cognitively challenging physical activities into early childhood education. Interventions combining cognitive and motor demands may contribute to the development of competencies relevant to both educational performance and long-term health. In line with existing evidence, future research may examine longitudinal effects, explore adaptations targeting strength and balance, and employ neurophysiological methods to clarify underlying mechanisms [22, 31, 32, 33].

The present work provides evidence for the cognitive and motor benefits of a motor intervention derived from Stroop principles in preschool children. By incorporating dynamic rule switching, audiovisual stimuli, and transitional motor play, the program was associated with functional improvements in executive attention and running performance. These findings are consistent with the theoretical foundations of embodied cognition and indicate practical relevance for teachers, therapists, and curriculum developers in supporting foundational skills during early developmental periods. The scalability and applicability of such interventions suggest their potential value for promoting academic readiness and self-regulation.

Limitations and Future Research

A relatively small sample size and the short duration of the intervention represent important limitations of the study and may restrict the generalizability of the findings. In addition, the absence of long-term follow-up measurements limits conclusions regarding the sustainability of the observed cognitive and motor effects. The study also focused on a specific age group and a limited set of motor outcomes, which may not fully capture the broader impact of motor–cognitive interventions across developmental stages.

Future research should examine the long-term effects of Stroop-based motor interventions through longitudinal designs and include larger and more diverse samples. Further studies may also explore adaptations of the program that target additional motor qualities, such as balance or strength, and assess outcomes in different educational and cultural contexts. The inclusion of neurophysiological or neuroimaging measures could provide deeper insight into the mechanisms linking motor activity, executive attention, and brain development.

Practical Implications

Adopting such programs in alignment with local cultural practices and educational structures may contribute to reducing developmental disparities and promoting equitable neurocognitive development during critical periods of brain maturation. This underscores the practical relevance of the intervention and supports its potential application as a model for educational innovation in the region.

Conclusions

The present research provides empirical evidence supporting the effectiveness of a transitional motor intervention based on visual response reversal derived from the Stroop task in enhancing executive attention and motor performance in preschool children. The integration of rule switching, response inhibition, and dynamic motor patterns within interactive play sessions was associated with significant improvements in Stroop test accuracy and running speed. These findings highlight the close relationship between embodied cognition and executive functions and demonstrate the value of structured, cognitively enriched movement programs in early education.

From a practical perspective, the results emphasize the importance of combining cognitive challenges with motor activities to support school readiness, self-regulation, and basic motor competence. The scalability and adaptability of the program suggest its relevance for broader educational and clinical applications aimed at supporting neurocognitive development. In early education systems in Arab and developing countries, where structured motor–cognitive interventions are less frequently implemented, these findings provide support for integrating evidence-based embodied learning strategies into kindergarten curricula.

Conflict of Interest

The authors report no conflict of interest.

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