



Multi-component motor-cognition physical activity model to improve executive function and physical intelligence in primary school students

Mejora de la fuerza muscular y la composición corporal tras entrenamiento de resistencia de baja carga con restricción del flujo sanguíneo e hipoxia en varones no entrenados

Authors

Nirut Sukdee¹
Werasak Wisalaporn²
Praphinwit Pokard²
Sakdarin Thammawong¹

¹Thailand National Sports University, Udonthani Campus (Thailand)

²Thailand National Sports University (Thailand)

Corresponding author:
Sakdarin Thammawong
Thsakdarin@gmail.com

Received: 23-01-26
Accepted: 09-03-26

How to cite in APA

Sukdee, N., Wisalaporn, W., Pokard, P., & Thammawong, S. (2026). Multi-component motor-cognition physical activity model to improve executive function and physical intelligence in primary school students. *Retos*, 79, 286-296. <https://doi.org/10.47197/retos.v79.118636>

Abstract

Introduction: Cognitively engaging physical activity is increasingly recognized as a promising approach for supporting both motor competence and executive function during late childhood.

Objective: This study aimed to develop and examine the temporal changes associated with a Multi-Component Motor-Cognition Physical Activity (MPA) Model designed to enhance Physical Intelligence Quotient (PIQ) and Executive Function (EF) in primary school students.

Methodology: A one-group repeated measures design was employed with 40 children (aged 10–12) participating in an eight-week school-based intervention integrating yoga, rhythmic activities, resistance exercises, jogging, and culturally grounded Thai folk plays. Assessments occurred at baseline, mid-intervention (Week 4), and post-intervention (Week 8). PIQ was evaluated via the MOBAK battery, while EF was assessed through performance-based neurocognitive tasks (TMT-A/B, Flanker, and DFT). Analysis included repeated measures ANOVA with Bonferroni-adjusted post-hoc comparisons and partial eta squared (η^2) for estimating within-subject effect sizes.

Results: Findings indicated statistically significant improvements across all PIQ and EF indicators over time ($p < .05$). Post-intervention scores were consistently superior to baseline and mid-intervention values across both motor competence and executive function measures. Reductions in completion and reaction times, alongside increased design fluency and motor competence, reflected systematic performance improvements with medium-to-large effects across the intervention period.

Conclusions: Participation in a cognitively engaging MPA model was associated with concurrent improvements in motor competence and executive function. Although causal comparisons with alternative approaches cannot be established, the findings support the feasibility of integrated motor-cognitive models and provide a preliminary empirical foundation for future controlled trials.

Keywords

Executive function; physical intelligence quotient; cognitively engaging physical activity; motor competence; repeated measures; traditional games.

Resumen

Introducción: La actividad física cognitivamente estimulante se reconoce cada vez más como un enfoque prometedor para apoyar tanto la competencia motora como la función ejecutiva durante la niñez tardía.

Objetivo: Este estudio tuvo como objetivo desarrollar y examinar los cambios temporales asociados con un Modelo Multicomponente de Actividad Física Motora-Cognitiva (AMPC) diseñado para mejorar el Cociente de Inteligencia Física (CIF) y la Función Ejecutiva (FE) en estudiantes de primaria.

Metodología: Se empleó un diseño de medidas repetidas de un solo grupo con 40 niños (de 10 a 12 años) que participaron en una intervención escolar de ocho semanas que integró yoga, actividades rítmicas, ejercicios de resistencia, trote y juegos folclóricos tailandeses con base cultural. Las evaluaciones se realizaron al inicio, a mitad de la intervención (Semana 4) y después de la intervención (Semana 8). El CIF se evaluó mediante la batería MOBAK, mientras que la FE se evaluó mediante tareas neurocognitivas basadas en el desempeño (TMT-A/B, Flanker y DFT). El análisis incluyó un ANOVA de medidas repetidas con comparaciones post hoc ajustadas mediante la corrección de Bonferroni y eta cuadrado parcial (η^2) para estimar el tamaño del efecto intrasujeto.

Resultados: Los hallazgos indicaron mejoras estadísticamente significativas en todos los indicadores de CI de rendimiento y función ejecutiva a lo largo del tiempo ($p < 0,05$). Las puntuaciones posteriores a la intervención fueron consistentemente superiores a los valores basales y a mitad de la intervención, tanto en las medidas de competencia motora como de función ejecutiva. Las reducciones en los tiempos de finalización y reacción, junto con una mayor fluidez en el diseño y competencia motora, reflejaron mejoras sistemáticas en el rendimiento con efectos de moderados a grandes durante el período de intervención.

Conclusiones: La participación en un modelo de actividad física multimodal cognitivamente estimulante se asoció con mejoras concurrentes en la competencia motora y la función ejecutiva. Si bien no se pueden establecer comparaciones causales con enfoques alternativos, los hallazgos respaldan la viabilidad de los modelos integrados motor-cognitivos y proporcionan una base empírica preliminar para futuros ensayos controlados.

Palabras clave

Función ejecutiva; coeficiente intelectual físico; actividad física cognitivamente atractiva; competencia motora; medidas repetidas; juegos tradicionales.

Introduction

Executive function (EF) is a higher-order cognitive system responsible for self-regulation, goal-directed behavior, and adaptive decision-making (Diamond, 2013). The three core components of EF as inhibitory control, working memory, and cognitive flexibility support academic achievement, emotional regulation, and social adjustment throughout childhood (Best & Miller, 2010). Enhancing EF during late childhood is particularly important because this developmental period is characterized by rapid maturation of prefrontal cortical networks that underpin complex cognitive operations (Casey et al., 2005). Strengthening EF among primary school students, therefore, contributes directly to their learning potential and long-term capacity to meet increasing cognitive demands in modern societies (Álvarez-Bueno et al., 2017). Within contemporary educational environments, school-based physical activity has increasingly been recognized as a context through which children may simultaneously develop motor, cognitive, and socio-emotional capacities, thereby providing an integrative platform for holistic development (Hidayat et al., 2026). Such environments allow children to repeatedly coordinate attention, movement, and behavioral regulation within structured learning situations, potentially strengthening the interaction between cognitive control processes and everyday classroom functioning.

Growing evidence highlights the role of physical activity (PA) as a key, modifiable factor for promoting EF through both neurobiological and behavioral pathways. The Motor-Cognition Link posits that motor competence (MC) the proficiency in performing coordinated and adaptive motor tasks and EF share overlapping neural substrates, particularly in cerebellar-prefrontal circuits that support coordinated movement and executive control (Hillman et al., 2008). In the present study, MC is operationalized through the construct of physical intelligence, often conceptualized as Physical Intelligence Quotient (PIQ), which reflects the capacity to perform coordinated, efficient, and adaptive motor actions in response to environmental demands (Utesch et al., 2019). PA that requires precise whole-body coordination is thought to enhance automaticity of movement, reduce the cognitive resources needed for basic motor execution, and free capacity for higher-order executive processes (Tomprowski et al., 2015). Meta-analytic evidence suggests that regular engagement in PA contributes to improvements in attention, cognitive flexibility, and inhibitory control in school-age children (de Greeff et al., 2018; Sember et al., 2020). Performance-based assessments such as the MOBAC battery provide reliable indices of children's self-movement and object-movement skills and are positively associated with EF and academic outcomes (Willoughby et al., 2021; Bao et al., 2024). From a developmental perspective, interventions that enhance PIQ through structured PA may also promote EF by stimulating neural systems involved in motor planning and executive control (Spanou et al., 2022). These relationships suggest that coordinated movement experiences may serve not only as physical training stimuli but also as functional contexts in which executive processes are repeatedly activated and refined.

Recent trends in the literature emphasize a shift from traditional aerobic exercise toward cognitively engaging physical activity (CEPA), which places higher demands on EF subdomains than simple, repetitive movement (Best, 2010; Hillman et al., 2014). The adoption of a Multi-Component Motor-Cognition Physical Activity (MPA) Model is justified by its capacity to provide a cognitively enriched movement environment that reflects the complex cognitive-motor interactions children encounter in authentic learning situations. CEPA includes open-skill activities that require real-time decision-making and rapid adaptation to changing task or environmental constraints (Crova et al., 2014; Mao et al., 2024). Systematic reviews indicate that such activities yield more consistent benefits for EF than low-complexity exercise, particularly when interventions are delivered over several weeks (Álvarez-Bueno et al., 2017; Song et al., 2023). Culturally grounded games and rhythmic activities may further enhance engagement and adherence, which are critical for sustaining developmental gains (Coppola et al., 2024). Within school-based physical education contexts, these culturally meaningful movement activities may also provide socially interactive learning environments that encourage cooperation, adaptive problem solving, and sustained participation. Such socially interactive movement contexts may also reinforce motivational and affective processes that support long-term engagement in physically and cognitively demanding activities.

Despite increasing evidence linking PA, PIQ, and EF, important gaps remain. Few longitudinal interventions have examined the sustained effects of multi-component PA models using objective performance-based measures across repeated time points (Zhao et al., 2024). Moreover, little is known about the



efficacy of culturally relevant open-skill activities, such as Thai folk plays, as vehicles for delivering CEPA within Asian school contexts (Mao et al., 2024). Understanding how these culturally grounded movement experiences interact with the socio-educational environment of schools is particularly important for determining the broader applicability of such interventions. Variations in school resources, pedagogical practices, and students' socio-cultural backgrounds may influence how movement-based programs are implemented and how their developmental benefits are realized. There is a need for studies that evaluate whether enriched PA can produce progressive patterns of change over time (Zeng et al., 2017; Tao et al., 2025).

Therefore, the present study aimed to develop and evaluate a Multi-Component Motor-Cognition Physical Activity (MPA) Model designed to enhance both PIQ and EF among primary school students in Grades 4–6. By combining yoga, rhythmic activities, resistance exercises, jogging, and Thai folk plays, this research seeks to examine how a structured MPA intervention implemented within a school environment may support children's motor coordination, cognitive regulation, and socio-emotional engagement. By assessing outcomes across repeated measurement points, the study further aims to determine whether such a multi-component program can produce progressive developmental changes in both motor competence and executive functioning over time. In doing so, the study aims to provide empirical evidence that can inform the development of evidence-based physical education practices capable of supporting children's holistic development within contemporary educational systems.

Method

Study Design

This study employed a quasi-experimental, one-group repeated-measures design to examine the effects of the Multi-Component Motor-Cognition Physical Activity (MPA) Model on Physical Intelligence Quotient (PIQ) and Executive Function (EF) in primary school students. Quasi-experimental one-group designs involve exposing a single group of participants to an intervention while measuring outcomes across multiple time points without the inclusion of a comparison group (Campbell & Stanley, 1963). Such designs are frequently adopted in school-based intervention research when the objective is to evaluate program-related changes within authentic educational environments where random assignment or control groups may be difficult to implement.

Measurements were conducted at three assessment points: baseline (Pre-test), Week 4 (Mid-test), and Week 8 (Post-test). This repeated-measures structure allows for the observation of intra-participant changes across time and facilitates the identification of progressive developmental patterns associated with the intervention rather than relying solely on pre–post comparisons (Shadish et al., 2002).

The inclusion of three assessment occasions enhances the analytical sensitivity of the design by enabling the identification of temporal trajectories of change across the intervention period. This approach allows researchers to examine whether improvements emerge gradually during the intervention or become evident primarily toward the later stages of program implementation.

Although quasi-experimental designs do not permit causal inference relative to alternative interventions, they provide a useful methodological framework for examining within-participant adaptations during the implementation of newly developed educational movement programs in real-world school settings.

Participants

The target population of this study consisted of upper primary school students (Grades 4–6) enrolled in the Thai basic education system. This developmental stage was selected because children aged 10–12 years experience substantial improvements in both motor competence and executive function abilities that are closely linked to learning and self-regulation (Best, 2010; Diamond, 2013). To determine the appropriate sample size, an a priori power analysis was conducted using G*Power software (Version 3.1.9.7) (Faul et al., 2009). Assuming a repeated-measures ANOVA design with three measurement occasions, a medium effect size ($f = .25$), an alpha level of .05, and statistical power of .80, the minimum required sample size was estimated at 28 participants.



To ensure sufficient statistical power and enhance analytical robustness, 40 students aged 10–12 years (20 boys and 20 girls) from a public primary school were recruited using stratified random sampling. Inclusion criteria required that participants were enrolled in Grades 4–6, had no medical conditions limiting participation in physical activity, obtained parental consent, and provided student assent. Exercise readiness was screened using the Physical Activity Readiness Questionnaire (PAR-Q). Ethical approval for the study was granted by the Institutional Review Board of Thailand National Sports University (Approval No.: TNSU-EDU 021-2025).

Intervention: Multi-Component Motor-Cognition Physical Activity Model

The Multi-Component Motor-Cognition Physical Activity (MPA) Model was designed to integrate movement experiences that simultaneously stimulate motor competence and cognitive engagement. The conceptual foundation of the model aligns with research suggesting that cognitively engaging physical activity can support improvements in executive functioning and cognitive processes relevant to academic performance (Alvarez-Bueno et al., 2017; Sember et al., 2020). Each training session lasted 45 minutes, conducted three times per week for eight consecutive weeks, and was implemented by trained physical education instructors. Sessions integrated several activity components:

- Yoga-based movements emphasizing balance and postural control
- Rhythmic movement sequences promoting coordination and timing
- Resistance and functional tasks supporting muscular control and motor planning
- Jogging and locomotor exercises targeting cardiovascular engagement and processing speed
- Thai folk plays.

Thai folk plays functioned as open-skill and socially interactive movement activities requiring rapid decision-making, attentional regulation, and inhibitory control (Best, 2010; Pesce et al., 2016).

The integration of these diverse movement modalities was intended to create cognitively enriched physical activity environments in which motor execution, attentional control, and decision-making processes occur simultaneously. Such conditions reflect the theoretical principles of cognitively engaging physical activity interventions, which propose that the coupling of cognitive and motor demands may facilitate executive function development.

Measures

Physical Intelligence (PIQ)

Physical intelligence was assessed using the MOBAK test battery, which evaluates fundamental motor competencies across two domains: self-movement (e.g., balancing, jumping) and object-movement (e.g., throwing, catching). Each domain yields scores ranging from 0 to 12 points, with higher scores indicating greater motor competence and adaptive physical performance (Herrmann & Seelig, 2017). Previous studies have reported that the MOBAK instrument demonstrates acceptable psychometric properties for assessing motor competence in primary school children, with reported Cronbach's alpha values ranging between .72 and .81 (Scheuer et al., 2020).

Executive Function (EF)

Executive function was evaluated using three performance-based neurocognitive instruments with established validity and reliability.

Trail Making Test (TMT-A and TMT-B)

The Trail Making Test assesses Attention Working memory and cognitive flexibility (Delis et al., 2001; Swanson, 2005). Performance is recorded as completion time in seconds, with shorter completion times reflecting more efficient cognitive processing. The difference score (TMT B–A) and ratio score (B/A) were also calculated as additional indicators of set-shifting efficiency.

Flanker Task

The Flanker task evaluates inhibitory control, attentional focus and Executive function (Colcombe et al., 2004; Pontifex & Hillman, 2007). Performance is quantified using reaction time in milliseconds (ms).



Shorter reaction times in incongruent trials indicate stronger inhibitory control.

Design Fluency Test (DFT)

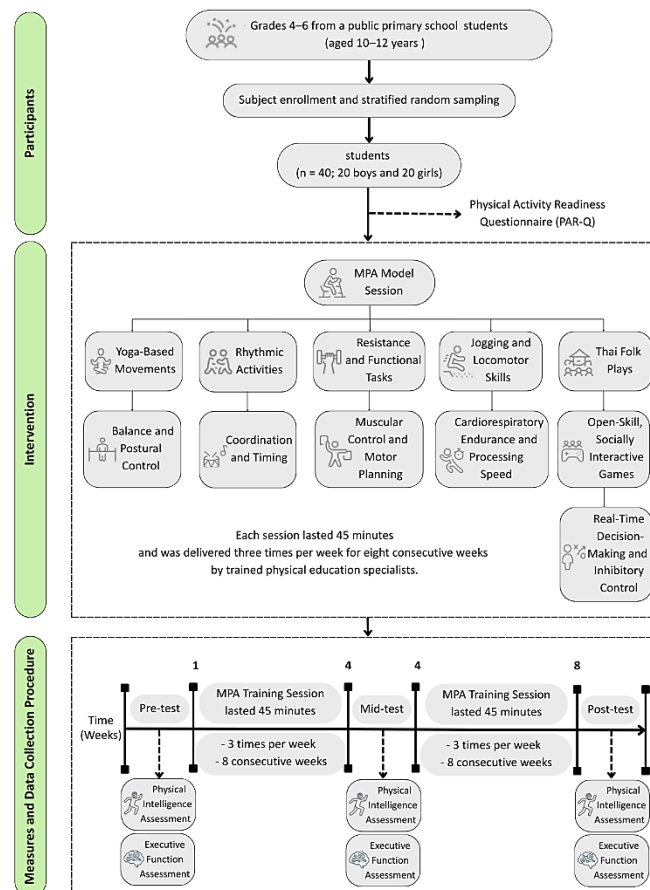
The Design Fluency Test assesses higher-order executive processes including cognitive flexibility, planning, generative fluency, and inhibitory control (Delis et al., 2001). Participants generate unique visual designs under time constraints, where higher scores reflect stronger executive functioning across fluency, switching, inhibition, and planning domains.

Data analysis

All statistical analyses were conducted using SPSS Version 28. Descriptive statistics (mean and standard deviation) were calculated for all variables. Repeated-measures ANOVA was used to examine within-participant changes across baseline, Week 4, and Week 8. The assumption of sphericity was evaluated using Mauchly's test, and when violations occurred, Greenhouse–Geisser corrections were applied (Field, 2024). Post-hoc pairwise comparisons were performed using Bonferroni adjustments. Effect sizes were reported using partial eta squared (η^2) and interpreted as .01 (small), .06 (medium), and .14 (large) (Cohen, 1988).

Reporting effect sizes alongside statistical significance provides additional information regarding the magnitude of intervention-associated changes and supports a more comprehensive interpretation of the results.

Figure 1. The methodology overview, a session, and the testing schedule.



Results

Repeated measures ANOVA revealed statistically significant within-participant changes in all Physical Intelligence Quotient (PIQ) and Executive Function (EF) outcomes across the three assessment points: baseline, Week 4, and Week 8 ($p < .001$ for all variables). Bonferroni-adjusted post-hoc comparisons indicated that performance at post-intervention (Week 8) was significantly improved relative to both baseline and mid-intervention, whereas Week 4 values consistently represented intermediate levels of performance, reflecting a progressive pattern of change across the three measurement occasions consistent with the repeated measures design.

For executive function outcomes, completion times on the Trail Making Test (TMT-A and TMT-B) decreased across measurement occasions, indicating improvements in processing speed and cognitive flexibility. Mean completion time for TMT-A decreased from 42.15 ± 6.92 seconds at baseline to 34.10 ± 5.38 seconds at Week 8 ($F(2,78) = 19.82, p < .001, \eta^2 = .34$). Similarly, TMT-B completion time declined from 73.88 ± 9.66 seconds to 60.78 ± 8.05 seconds across the intervention period ($F(2,78) = 26.51, p < .001, \eta^2 = .40$). Corresponding reductions in the TMT B–A difference score and the B/A ratio further indicated improved set-shifting performance across time points.

Reaction times in both congruent and incongruent conditions of the Flanker task also decreased across assessments, reflecting improvements in inhibitory control and attentional processing. Mean reaction time in the congruent condition decreased from 720.25 ± 62.90 ms at baseline to 660.80 ± 55.22 ms at Week 8 ($F(2,78) = 22.04, p < .001, \eta^2 = .36$), while incongruent reaction time decreased from 810.30 ± 71.45 ms to 745.13 ± 64.70 ms ($F(2,78) = 20.91, p < .001, \eta^2 = .35$). Improvements were observed across EF tasks with differing cognitive demands, indicating consistent within-participant changes across multiple executive domains rather than task-specific effects.

Higher-order executive processes assessed using the Design Fluency Test (DFT) also increased significantly across measurement occasions. Fluency scores increased from 19.25 ± 3.60 at baseline to 23.43 ± 3.35 at Week 8 ($F(2,78) = 18.78, p < .001, \eta^2 = .33$). Similar increases were observed for switching (14.18 ± 2.71 to 17.23 ± 2.43 ; $F(2,78) = 15.50, p < .001, \eta^2 = .29$), inhibition (13.90 ± 2.60 to 17.05 ± 2.30 ; $F(2,78) = 16.32, p < .001, \eta^2 = .30$), and planning (12.93 ± 2.51 to 16.15 ± 2.12 ; $F(2,78) = 17.81, p < .001, \eta^2 = .31$).

With respect to physical intelligence, both MOBAK self-movement and object-movement scores increased significantly across the three assessment points. MOBAK object-movement scores increased from 7.45 ± 1.92 at baseline to 9.70 ± 1.65 at Week 8 ($F(2,78) = 24.91, p < .001, \eta^2 = .39$), while MOBAK self-movement scores increased from 8.30 ± 1.76 to 10.78 ± 1.42 ($F(2,78) = 31.43, p < .001, \eta^2 = .45$). These results indicate improvements in motor coordination, balance, and object-control performance across the intervention period.

Across all EF and PIQ outcomes, partial eta squared values ranged from .24 to .45, indicating medium-to-large within-subject effect sizes. Collectively, the results show consistent within-participant improvements across executive function and motor competence measures over time, while detailed descriptive statistics and inferential analyses are presented in Table 1.

Table 1. Descriptive Statistics, Repeated Measures ANOVA Results, and Effect Sizes for PIQ and EF Outcomes (N = 40)

Domain	Variable	Pre-test M \pm SD	Week 4 M \pm SD	Week 8 M \pm SD	F (2,78)	p	η^2
PIQ	MOBAK Object Movement	7.45 \pm 1.92	8.68 \pm 1.74	9.70 \pm 1.65	24.91	< .001	.39
	MOBAK Self-Movement	8.30 \pm 1.76	9.60 \pm 1.68	10.78 \pm 1.42	31.43	< .001	.45
EF – Processing Speed / Flexibility	TMT-A (sec)	42.15 \pm 6.92	38.25 \pm 6.10	34.10 \pm 5.38	19.82	< .001	.34
	TMT-B (sec)	73.88 \pm 9.66	67.40 \pm 8.88	60.78 \pm 8.05	26.51	< .001	.40
	TMT B–A (sec)	31.73 \pm 5.15	29.15 \pm 4.92	26.68 \pm 4.23	16.63	< .001	.30
	TMT B/A Ratio	1.76 \pm 0.21	1.71 \pm 0.19	1.66 \pm 0.18	12.54	< .001	.24
EF – Inhibition / Attention	Flanker Congruent RT (ms)	720.25 \pm 62.90	697.43 \pm 58.11	660.80 \pm 55.22	22.04	< .001	.36
	Flanker Incongruent RT (ms)	810.30 \pm 71.45	782.88 \pm 68.55	745.13 \pm 64.70	20.91	< .001	.35
EF – Higher-order Control	DFT Fluency	19.25 \pm 3.60	21.15 \pm 3.52	23.43 \pm 3.35	18.78	< .001	.33
	DFT Switching	14.18 \pm 2.71	15.83 \pm 2.52	17.23 \pm 2.43	15.50	< .001	.29
	DFT Inhibition	13.90 \pm 2.60	15.45 \pm 2.48	17.05 \pm 2.30	16.32	< .001	.30
	DFT Planning	12.93 \pm 2.51	14.55 \pm 2.38	16.15 \pm 2.12	17.81	< .001	.31

Note: Lower scores indicate better performance for TMT and Flanker tasks, whereas higher scores indicate better performance for MOBAK and DFT measures.



Discussion

The present study examined within-participant changes in Physical Intelligence Quotient (PIQ) and Executive Function (EF) following participation in a multi-component motor–cognition physical activity model delivered over an eight-week period. The findings demonstrated consistent improvements across all assessed motor and executive domains from baseline through mid- and post-intervention assessments. These results align with theoretical accounts of the motor–cognition link, which posit that motor competence and executive control co-develop through shared neural and behavioral mechanisms (Hillman et al., 2008; Spanou et al., 2022). Within school-based environments, movement experiences that simultaneously engage coordination, attention, and decision-making may provide a functional learning context in which motor and cognitive processes are exercised in parallel rather than in isolation. Such environments allow children to repeatedly coordinate perception, action, and behavioral regulation, supporting the gradual integration of motor proficiency with executive control processes during development. Integrated activity structures provide a holistic-integrative platform for early childhood development across motor, emotional, and cognitive domains simultaneously (Hidayat et al., 2026). In this sense, the intervention examined in the present study can be interpreted as creating a learning ecology in which physical activity functions not only as a health-related behavior but also as a context for cognitive engagement and behavioral regulation.

Improvements observed in Trail Making Test and Flanker task performance suggest enhanced processing speed, cognitive flexibility, and inhibitory control—core EF components essential for learning and classroom functioning (Best & Miller, 2010; Diamond, 2013). Importantly, the consistency of improvements across multiple EF tasks with distinct cognitive demands reduces the likelihood that the observed changes can be attributed solely to task-specific practice effects. Rather, the pattern of findings is consistent with previous evidence indicating that sustained engagement in cognitively engaging physical activity supports adaptive executive functioning in children (de Greeff et al., 2018; Mao et al., 2024; Song et al., 2023). Programs implemented in school contexts that combine physical exertion with coordination and attentional demands appear particularly relevant for EF development because they mirror the complex cognitive–motor interactions children encounter during real-world learning activities. These interactions often require children to integrate sensory information, anticipate environmental changes, and regulate motor responses, processes that closely correspond to the executive functions assessed in the present study. Recent research suggests that interventions integrating motor coordination and cognitive demands can support children’s attentional control and cognitive flexibility when implemented within regular educational environments (Pérez-Herráez et al., 2025).

The integration of Thai folk plays and rhythmic activities may have contributed to these outcomes by increasing cognitive demands during physical activity. Such activities require continuous monitoring, rapid decision-making, and behavioral regulation in dynamic social contexts, which are defining characteristics of cognitively engaging physical activity (CEPA) (Best, 2010; Crova et al., 2014). Meta-analytic evidence indicates that physical activity interventions characterized by higher cognitive and coordinative demands yield more consistent EF benefits than repetitive or low-complexity exercise (Álvarez-Bueno et al., 2017; Sember et al., 2020). Traditional games and culturally embedded movement activities may also introduce elements of unpredictability and cooperation, encouraging children to continuously adapt actions in response to changing social and spatial conditions. Such adaptive demands may strengthen the coupling between perception, decision-making, and motor execution, which is considered a key mechanism underlying cognitively engaging movement activities. In addition, evidence from school intervention studies suggests that socially interactive and game-based activities may enhance children’s engagement and motivation, which may indirectly support sustained participation and learning (López-Fernández et al., 2024).

Parallel improvements in MOBAK self-movement and object-movement scores indicate enhanced motor competence across the intervention period. From a developmental perspective, improvements in motor competence may reduce the attentional resources required for movement execution, thereby facilitating more efficient engagement of executive processes (Stodden et al., 2008; Utesch et al., 2019). The concurrent improvements observed in PIQ and EF are therefore consistent with models proposing reciprocal relationships between motor and cognitive development during childhood (Willoughby et al., 2021; Bao et al., 2024). Within this framework, improvements in motor proficiency may gradually support



more efficient cognitive regulation during coordinated movement tasks, particularly in environments where children must adapt actions in response to changing spatial and social cues. Consequently, the observed improvements in both domains may reflect complementary developmental processes rather than independent adaptations. This interpretation is consistent with developmental models suggesting that motor competence and executive control evolve through mutually reinforcing processes across childhood.

From an applied standpoint, the findings suggest that integrating structured, multi-component physical activity programs emphasizing coordination, variability, and cognitive engagement may be a promising approach within school-based physical education. However, these findings should be interpreted within the boundaries of the study design. The use of a one-group repeated measures approach limits causal inference and does not permit conclusions regarding the comparative effectiveness of the intervention relative to alternative physical activity formats. Additionally, potential confounding influences including natural developmental maturation, familiarity with repeated cognitive testing, and parallel learning experiences occurring within the school environment may also have contributed to the observed changes. These contextual factors should therefore be considered when interpreting improvements observed across repeated measurement points in school-based intervention studies. To mitigate these concerns, future programs should also consider the interdependence of the school and family environments to ensure long-term sustainability (López-Fernández et al., 2024; Pérez-Herráez et al., 2025). Future studies employing randomized controlled designs, longer follow-up periods, and neurophysiological measures are warranted to clarify the durability and mechanisms underlying motor-cognitive adaptations (Hillman et al., 2014; Tao et al., 2025; Zhao et al., 2024).

Conclusions

The present study investigated within-participant changes in Physical Intelligence Quotient (PIQ) and Executive Function (EF) associated with participation in an eight-week multi-component motor-cognition physical activity model among upper primary school students. The findings demonstrated consistent and systematic improvements across all assessed motor competence and executive function measures from baseline through mid- and post-intervention assessments, indicating progressive patterns of change across the intervention period. These results suggest that structured movement experiences characterized by coordinative complexity and cognitive demands such as Thai folk plays may create developmentally meaningful learning contexts in which motor coordination, attentional regulation, and executive processes are engaged simultaneously during physical activity participation. In this sense, the intervention can be interpreted as a cognitively enriched movement environment in which perception, action, and behavioral regulation are repeatedly integrated through dynamic and socially interactive movement tasks. Furthermore, the findings support the view of physical activity as a multidimensional developmental platform capable of engaging motor, cognitive, and socio-emotional processes within everyday educational environments.

From an educational perspective, the findings support the practical feasibility of implementing cognitively engaging, multi-component physical activity models within authentic school settings. Programs that combine coordinative challenges, decision-making demands, and socially interactive activities may resemble the complex cognitive-motor interactions children encounter during everyday learning experiences. Such movement environments may provide opportunities for children to practice adaptive responses, attentional control, and behavioral regulation while simultaneously developing motor competence. In addition, the integration of game-based and socially interactive activities may contribute to higher levels of engagement and sustained participation, which are important conditions for effective school-based physical activity initiatives.

However, these findings should be interpreted within the methodological boundaries of the study. Given the quasi-experimental, one-group repeated measures design, the results reflect within-participant developmental adaptations observed across the intervention period rather than causal superiority relative to alternative approaches. Although the repeated measurement structure allowed the identification of temporal trajectories of change across the program duration, several contextual factors including natural developmental maturation, familiarity with repeated cognitive testing, and parallel learning experiences within the school environment may also have contributed to the observed improvements. Future



research employing randomized controlled designs, active comparison conditions, longer follow-up periods, and complementary neurophysiological assessments will be important for clarifying the durability, stability, and underlying mechanisms of the motor–cognitive adaptations observed in this study.

Acknowledgements

This study is supported by the Thailand National Sports University Fund. We would also like to thank all the participants who volunteered in this study and the Faculty of Physical Education, Thailand National Sports University, Udonthani Campus, for providing the relevant equipment used in this study.

Financing

The authors thank Thailand National Sports University, Udonthani Campus, for the financial support.

References

- Alvarez-Bueno, C., Pesce, C., Caverro-Redondo, I., Sanchez-Lopez, M., Martínez-Hortelano, J. A., & Martínez-Vizcaino, V. (2017). The effect of physical activity interventions on children's cognition and metacognition: A systematic review and meta-analysis. *Journal of the American Academy of Child & Adolescent Psychiatry, 56*(9), 729-738. <https://doi.org/10.1016/j.jaac.2017.06.012>
- Bao, R., Wade, L., Leahy, A. A., Owen, K. B., Hillman, C. H., Jaakkola, T., & Lubans, D. R. (2024). Associations between motor competence and executive functions in children and adolescents: A systematic review and meta-analysis. *Sports Medicine, 54*(8), 2141-2156. <https://doi.org/10.1007/s40279-024-02040-1>
- Best, J. R. (2010). Effects of physical activity on children's executive function: Contributions of experimental research on aerobic exercise. *Developmental review, 30*(4), 331-351. <https://doi.org/10.1016/j.dr.2010.08.001>
- Best, J. R., & Miller, P. H. (2010). A developmental perspective on executive function. *Child development, 81*(6), 1641-1660. <https://doi.org/10.1111/j.1467-8624.2010.01499.x>
- Campbell, D. T., & Stanley, J. C. (1963). *Experimental and quasi-experimental designs for research*. Ravenio books.
- Casey, B. J., Tottenham, N., Liston, C., & Durston, S. (2005). Imaging the developing brain: what have we learned about cognitive development?. *Trends in cognitive sciences, 9*(3), 104-110. <https://doi.org/10.1016/j.tics.2018.11.006>
- Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Routledge. <https://doi.org/10.4324/9780203771587>
- Colcombe, S. J., Kramer, A. F., Erickson, K. I., Scalf, P., McAuley, E., Cohen, N. J., ... & Elavsky, S. (2004). Cardiovascular fitness, cortical plasticity, and aging. *Proceedings of the National Academy of Sciences, 101*(9), 3316-3321. <https://doi.org/10.1073/pnas.0400266101>
- Coppola, S., Matrisciano, C., & Vastola, R. (2024). Exploring the relationship between physical activity and cognitive function in children. *Journal of Physical Education and Sport, 24*(5), 1266-1274. <https://doi:10.7752/jpes.2024.05144>
- Crova, C., Struzzolino, I., Marchetti, R., Masci, I., Vannozzi, G., Forte, R., & Pesce, C. (2014). Cognitively challenging physical activity benefits executive function in overweight children. *Journal of sports sciences, 32*(3), 201-211. <https://doi.org/10.1080/02640414.2013.828849>
- De Greeff, J. W., Bosker, R. J., Oosterlaan, J., Visscher, C., & Hartman, E. (2018). Effects of physical activity on executive functions, attention and academic performance in preadolescent children: a meta-analysis. *Journal of science and medicine in sport, 21*(5), 501-507. <https://doi.org/10.1016/j.jsams.2017.09.595>
- Delis, D. C., Kaplan, E., & Kramer, J. H. (2001). *Delis-Kaplan executive function system (D-KEFS)*. Psychological Corporation.
- Diamond, A. (2013). Executive functions. *Annual review of psychology, 64*(1), 135-168. <https://doi.org/10.1146/annurev-psych-113011-143750>
- Faul, F., Erdfelder, E., Buchner, A., & Lang, A. G. (2009). Statistical power analyses using G* Power 3.1:



- Tests for correlation and regression analyses. *Behavior research methods*, 41(4), 1149-1160. <https://doi.org/10.3758/BRM.41.4.1149>
- Field, A. (2024). *Discovering statistics using IBM SPSS statistics*. Sage publications limited. Herrmann, C., & Seelig, H. (2017). Basic motor competencies of fifth graders: Construct validity of the MOBAK-5 test instrument and determinants. *German Journal of Exercise and Sport Research*, 47(2), 110-121. <https://doi.org/10.1007/s12662-016-0430-3>
- Hidayat, A. K., Setyawati, H., Hidayatullah, F., & Hartono, M. (2026). Effect of physical activity on kindergarten students' motor skills, emotional and cognitive development: a systematic review. *Retos*, 74, 166-184. <https://doi.org/10.47197/retos.v74.117447>
- Hillman, C. H., Erickson, K. I., & Kramer, A. F. (2008). Be smart, exercise your heart: exercise effects on brain and cognition. *Nature reviews neuroscience*, 9(1), 58-65. <https://doi.org/10.1038/nrn2298>
- Hillman, C. H., Pontifex, M. B., Castelli, D. M., Khan, N. A., Raine, L. B., Scudder, M. R., ... & Kamijo, K. (2014). Effects of the FITKids randomized controlled trial on executive control and brain function. *Pediatrics*, 134(4), e1063-e1071. <https://doi.org/10.1542/peds.2013-3219>
- López-Fernández, I., Mayorga-Vega, D., Guijarro-Romero, S., & Viciano, J. (2024). Participants' opinions in an intervention to promote physical activity in the school context: Fit-Person Study. *Retos*, 55, 1053-1062. <http://dx.doi.org/10.47197/retos.v55.106263>
- Mao, F., Huang, F., Zhao, S., & Fang, Q. (2024). Effects of cognitively engaging physical activity interventions on executive function in children and adolescents: a systematic review and meta-analysis. *Frontiers in Psychology*, 15, 1454447. <https://doi.org/10.3389/fpsyg.2024.1454447>
- Pérez-Herráez, I., Valencia-Peris, A., & Velert, C. P. (2025). School-based interventions to promote physical activity from preschool through high school: A systematic review. *Retos*, 63, 128. <https://doi.org/10.47197/retos.v63.109>
- Pesce, C., Masci, I., Marchetti, R., Vazou, S., Säakslähti, A., & Tomporowski, P. D. (2016). Deliberate play and preparation jointly benefit motor and cognitive development: mediated and moderated effects. *Frontiers in psychology*, 7, 349. <https://doi.org/10.3389/fpsyg.2016.00349>
- Pontifex, M. B., & Hillman, C. H. (2007). Neuroelectric and behavioral indices of interference control during acute cycling. *Clinical Neurophysiology*, 118(3), 570-580. <https://doi.org/10.1016/j.clinph.2006.09.029>
- Scheuer, C., Herrmann, C., & Bund, A. (2019). Motor tests for primary school aged children: A systematic review. *Journal of sports sciences*, 37(10), 1097-1112. <https://doi.org/10.1080/02640414.2018.1544535>
- Sember, V., Jurak, G., Kovač, M., Morrison, S. A., & Starc, G. (2020). Children's physical activity, academic performance, and cognitive functioning: a systematic review and meta-analysis. *Frontiers in public health*, 8, 536635. <https://doi.org/10.3389/fpubh.2020.00307>
- Shadish, W. R., Cook, T. D., & Campbell, D. T. (2002). *Experimental and quasi-experimental designs for generalized causal inference*. Boston: Houghton Mifflin.
- Song, Y., Fan, B., Wang, C., & Yu, H. (2023). Meta-analysis of the effects of physical activity on executive function in children and adolescents with attention deficit hyperactivity disorder. *PLoS One*, 18(8), e0289732. <https://doi.org/10.1371/journal.pone.0289732>
- Spanou, M., Kaioglou, V., Pesce, C., Mavilidi, M. F., & Venetsanou, F. (2022). "Move" their brain: motor competence mediates the relationship of physical activity and executive functions in children. *Applied Sciences*, 12(20), 10527. <https://doi.org/10.3390/app122010527>
- Stodden, D. F., Goodway, J. D., Langendorfer, S. J., Robertson, M. A., Rudisill, M. E., Garcia, C., & Garcia, L. E. (2008). A developmental perspective on the role of motor skill competence in physical activity: An emergent relationship. *Quest*, 60(2), 290-306. <https://doi.org/10.1080/00336297.2008.10483582>
- Swanson, J. (2005). The Delis-Kaplan executive function system: a review. *Canadian Journal of School Psychology*, 20(1-2), 117-128. <https://doi.org/10.1177/0829573506295469>
- Tao, Y., Zhang, Y., Qian, H., & Cao, Z. (2025). Long term effects of physical activity types on executive functions in school aged children. *Scientific Reports*, 15(1), 30303. <https://doi.org/10.1038/s41598-025-09674-9>
- Tomporowski, P. D., McCullick, B., Pendleton, D. M., & Pesce, C. (2015). Exercise and children's cognition: The role of exercise characteristics and a place for metacognition. *Journal of Sport and Health Science*, 4(1), 47-55. <http://dx.doi.org/10.1016/j.jshs.2014.09.003>

- Utesch, T., Bardid, F., Büsch, D., & Strauss, B. (2019). The relationship between motor competence and physical fitness from early childhood to early adulthood: a meta-analysis. *Sports medicine*, 49(4), 541-551. <https://doi.org/10.1007/s40279-019-01068-y>
- Willoughby, M., Hudson, K., Hong, Y., & Wylie, A. (2021). Improvements in motor competence skills are associated with improvements in executive function and math problem-solving skills in early childhood. *Developmental Psychology*, 57(9), 1463. <https://psycnet.apa.org/doi/10.1037/dev0001223>
- Zeng, N., Ayyub, M., Sun, H., Wen, X., Xiang, P., & Gao, Z. (2017). Effects of physical activity on motor skills and cognitive development in early childhood: a systematic review. *BioMed research international*, 2017(1), 2760716. <https://doi.org/10.1155/2017/2760716>
- Zhao, J., Xiang, C., Fadilah, T. K. T., & Luo, H. (2024). The effects of physical activity interventions on children's perception: A systematic review and meta-analysis. *Journal of Sports Science & Medicine*, 23(2), 289-305. <https://doi.org/10.52082/jssm.2024.289>

Authors' and translators' details:

Nirut Sukdee
Werasak Wisalaporn
Praphinwit Pokard
Sakdarin Thammawong

Ter.nirut28@gmail.com
Tnsu.psd@gmail.com
A.pokard@gmail.com
Thsakdarin@gmail.com

Author
Author
Author
Author / Translator