



Impact of a 12-Week Combined Object-Control and Aerobic Circuit Intervention on FMS Proficiency, Physical Activity, and Motor-Competence in Children: A Path-Analysis Approach

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Received: 19 November, 2025; Revised: 10 December, 2025; Accepted: 22 December, 2025; Published: 30 December, 2025.

Abstract

Introduction: Fundamental motor skills (FMS) play a vital role in developing children's motor competence and encouraging lifelong engagement in physical activity (PA).

Objective: This research investigated the impact of a 12-week intervention combining object-control and aerobic circuit training on FMS proficiency, PA levels, and overall motor competence among primary school children.

Methods: A total of 143 children, comprising 72 in the intervention group and 71 in the control group, aged between 8 and 10 years, participated in the study. The intervention group engaged in a 12-week program that combined object-control skill drills with aerobic circuits, while the control group received standard physical education. TGMD-3, BOT-2 and accelerometer were used for measuring research variables. Path analysis was conducted for data analysis.

Results: The intervention group exhibited significant enhancements in various physical performance metrics, including TGMD-3 locomotor scores ($\Delta=+6.5$, $p<.001$) and object-control scores ($\Delta=+7.5$, $p<.001$), as well as BOT-2 motor competence ($\Delta=+7.9$, $p<.001$). Additionally, there was a significant increase in daily MVPA ($p<.001$) compared to the control group. Path analysis revealed that FMS had both direct effects on motor competence and indirect effects that were mediated by PA, with an indirect effect coefficient of $\beta_{\text{indirect}}=0.29$ (95% CI [0.18, 0.42], $p<.001$).

Conclusion: PA serves as a partial mediator in the relationship between skill proficiency and motor competence, underscoring the necessity of multicomponent programs to foster comprehensive motor development and enhance physical literacy.

Keywords: Child, Motor Skills, Physical Activity, Exercise Therapy, Motor Development

How to Cite: Sabzi AH. Impact of a 12-Week Combined Object-Control and Aerobic Circuit Intervention on FMS Proficiency, Physical Activity, and Motor-Competence in Children: A Path-Analysis Approach. Phys. Act. Child. 2025;2(2):87-94. doi: 10.22034/pach.2025.560762.1079

1. Introduction

Fundamental motor skills (FMS) are essential movement patterns that form the basis for children's engagement in physical activity (PA), sports, and play (1,2). These skills are generally divided into two categories: locomotor skills, such as running and jumping, and object-control skills, including throwing and catching (3). Together, they play a crucial role in developing motor competence (4). Proficiency in FMS is associated with increased participation in moderate-to-vigorous PA (MVPA), enhanced cardiovascular and musculoskeletal fitness, and healthier body compositions in children (1,5). In contrast, children who struggle with motor skills often display lower activity levels, diminished confidence in their movements, and a greater likelihood of sedentary behavior, which can lead to obesity and other health-related concerns (6,7).

Object-control skills are vital for participation in sports and structured games, encompassing activities such as throwing, catching, striking, and dribbling (1). These skills contribute significantly to the

development of hand-eye coordination, reaction time, and spatial awareness, which are crucial for engaging in organized PA (8). However, research indicates that school-aged children often exhibit less proficiency in object-control skills compared to locomotor skills, particularly among those with limited access to structured PA (9,10). This disparity underscores the necessity for targeted interventions aimed at enhancing object-control abilities while fostering overall motor competence.

Aerobic fitness and participation in structured cardiovascular activities are essential for promoting physical health, improving endurance, and fostering overall motor development (11-13). Research indicates that aerobic interventions, especially those designed as enjoyable, game-based activities, can enhance heart rate recovery, cardiorespiratory endurance, and children's participation in PA (14-16). Furthermore, there is a significant relationship between aerobic capacity and motor skills; children with superior aerobic fitness tend to exhibit greater proficiency in FMS (17). This correlation is likely attributed to



increased energy availability, enhanced movement confidence, and prolonged engagement in PA (18,19).

The integration of object-control skills and aerobic capacity is crucial for children's physical development, making the combination of object-control training with aerobic circuit activities an effective approach to enhance FMS, PA, and motor competence concurrently. Circuit training is particularly advantageous in school environments, as it facilitates frequent skill practice through diverse activity stations, promoting engagement in both skill-specific and fitness-related tasks (20,12). By incorporating stations focused on object-control skills, aerobic exercises such as shuttle runs and jumping jacks, and integrative challenges that blend movement with cognitive tasks, this comprehensive strategy can lead to significant improvements in targeted skills, overall motor coordination, endurance, and PA levels (23).

Despite the increasing interest in integrated skill and fitness programs, our understanding of the connections between structured training, FMS proficiency, PA, and overall motor competence remains limited. Most existing research has concentrated on either skill-specific interventions, such as object-control training, or aerobic training in isolation, often relying on straightforward pre- and post-intervention comparisons (23). While these studies demonstrate that targeted interventions can enhance specific outcomes, they overlook the intricate, interrelated dynamics among various skills, activity behaviors, and comprehensive motor competence. This limitation highlights the necessity for path-analysis methodologies, which enable researchers to investigate both the direct and indirect impacts of interventions on multiple outcomes, thereby offering a deeper insight into the developmental processes involved.

Path analysis, a component of structural equation modeling, facilitates the concurrent assessment of proposed relationships among observed variables, including both mediating and moderating effects (24). In the realm of children's motor development, path analysis can elucidate whether enhancements in object-control skills directly improve motor competence, whether increased PA serves as a mediator between skill proficiency and motor competence, and whether aerobic conditioning plays an independent role in fostering developmental progress. By delineating these pathways, researchers can provide evidence that informs the design of interventions, identifies key influencing factors, and ultimately improves program effectiveness.

The school setting is particularly well-suited for the implementation of PA interventions. Primary schools provide access to large groups of children within organized schedules, including physical education classes and playgrounds that facilitate circuit-based activities (25). These school-based initiatives also ensure equitable access, reaching children who may not have opportunities for extracurricular PA. Additionally, integrating skill and aerobic training into the school curriculum promotes consistent engagement, structured progression, and high fidelity, all of which are essential for achieving significant enhancements in motor skills and PA levels (26).

This study seeks to fill existing research gaps by examining the effects of a 12-week intervention that combines object-control and aerobic circuit training on FMS proficiency, PA levels, and overall motor

competence in primary-school children. Utilizing a path-analysis methodology, the research will assess both the direct impacts of the intervention on these outcomes and the indirect effects mediated through PA. This analytical framework provides a thorough understanding of the interplay between skill acquisition and aerobic fitness in fostering children's motor development.

The study aims to achieve three primary objectives: first, to assess the effectiveness of a 12-week program that combines object-control and aerobic circuit training in improving FMS; second, to analyze the effects of this intervention on objectively measured levels of PA; and third, to explore the relationships between enhancements in FMS proficiency, PA, and overall motor competence through path analysis. It is anticipated that children engaged in the combined intervention will show marked improvements in object-control skills, increased daily PA, and greater motor competence when compared to a control group participating in traditional physical education activities. Furthermore, the study posits that PA will serve as a mediating factor in the relationship between skill development and motor competence, underscoring the interconnectedness of these elements.

2. Methods

2.1. Study Design

This research utilized a quasi-experimental design featuring pretest and posttest assessments, incorporating both an intervention group and a control group. The main aim was to assess the impact of a 12-week program that combined object-control and aerobic circuit training on children's FMS, levels of PA, and overall motor competence. Furthermore, path analysis was performed to explore both direct and indirect relationships among these variables.

2.2. Participants

A total of 143 primary school children, aged between 8 and 10 years, were recruited from two public schools located in an urban area. A total of 143 participants were included in the study, and an a priori power analysis using G*Power 3.1 indicated that this sample size was sufficient to detect a medium effect size (Cohen's $d = 0.5$) with 80% power at an alpha level of 0.05. To qualify for the study, participants needed to be enrolled in grades 3 to 5, have no diagnosed neurological, musculoskeletal, or cardiovascular conditions, and be capable of safely engaging in MVPA. Exclusion criteria included any current injuries that would restrict PA and participation in organized sports outside of school for more than three hours per week. The children were randomly divided into an intervention group ($N = 72$) and a control group ($N = 71$). Prior to their involvement, parental consent and child assent were secured, and the study protocol was compliance with the principles outlined in the Declaration of Helsinki.

2.3. Intervention

The intervention involved a 12-week program of combined object-control and aerobic circuit training, conducted three times a week during physical education classes, with each session lasting 45 minutes

(21). Each session was structured around six stations, where participants engaged in activities such as throwing and catching with various object sizes, kicking and dribbling, shuttle runs and agility ladders for aerobic conditioning, jumping and hopping for plyometric and coordination development, skill integration combining object-control with locomotor movements, and aerobic endurance games like tag and mini-relays. The program progressively increased in difficulty by modifying factors such as distance, speed, object weight, and coordination complexity. To foster engagement and adherence, motivational strategies including positive feedback, peer interaction, and goal setting were implemented. In contrast, the control group participated in standard physical education classes that focused on general games and movement activities without the structured skill or aerobic circuits.

2.4. Measurements

2.4.1. Fundamental Motor Skill

FMS proficiency was evaluated through the Test of Gross Motor Development-Third Edition (TGMD-3), which assesses both locomotor skills - such as running, galloping, hopping, leaping, horizontal jumping, and sliding - and object-control skills, including throwing, catching, kicking, striking, dribbling, and underhand throwing (27). Each skill is scored based on specific performance criteria, with higher scores reflecting greater proficiency. The TGMD-3 has demonstrated strong inter-rater reliability, with an ICC ranging from 0.87 to 0.97, and it exhibits solid construct validity for children aged 3 to 10 years.

2.4.2. Motor Competence

The Bruininks-Oseretsky Test of Motor Proficiency-Second Edition (BOT-2), Short Form, was utilized to assess overall motor competence, encompassing fine motor skills, gross motor abilities, balance, strength, and coordination (28). The BOT-2 demonstrates robust test-retest reliability, with coefficients ranging from 0.80 to 0.90, and exhibits strong content validity for children aged 4 to 21 years.

2.4.3. Physical Activity

PA levels were quantitatively assessed using accelerometers (ActiGraph GT3X+), which participants

wore on their hips for a continuous period of seven days during waking hours. Non-wear time was identified as periods of 60 minutes or more with no recorded activity, and only data from days where the device was worn for at least 10 hours were considered valid. The primary outcome measured was the average daily duration of MVPA expressed in minutes. The ActiGraph accelerometers have been extensively validated for measuring PA in children, demonstrating strong criterion validity with correlation coefficients ranging from 0.75 to 0.90.

2.4.4. Demographic Data

Baseline demographic variables comprised age, sex, height, weight, and body mass index (BMI). Height and weight were assessed using a stadiometer and a calibrated scale, with BMI calculated as kg/m^2 .

2.5. Statistical Analysis

Preliminary analysis involved the use of descriptive statistics, including means and standard deviations, alongside independent t-tests to identify baseline differences between the groups. To evaluate the effects of the intervention, a 2×2 repeated-measures ANOVA was employed, focusing on changes in the TGMD-3, BOT-2, and MVPA metrics. Effect sizes were determined using partial eta squared (η^2). Path analysis was performed with AMOS 28.0 to explore both direct effects of the intervention on FMS proficiency, PA, and motor competence, as well as indirect effects mediated by PA. The model fit was assessed through CFI, TLI, RMSEA, and SRMR, adhering to acceptable fit criteria of $\text{CFI/TLI} \geq 0.90$, $\text{RMSEA} \leq 0.08$, and $\text{SRMR} \leq 0.08$. Statistical significance was established at $p < .05$, two-tailed.

3. Results

3.1. Participant Characteristics

A total of 143 children were involved in the study, with 72 assigned to the intervention group and 71 to the control group. Baseline comparisons revealed no significant differences between the groups regarding age, sex distribution, height, weight, or BMI ($p > .05$), confirming the effectiveness of the randomization process (Table 1).

Table 1. Participant Demographics at Baseline.

Variable	Intervention (n=72)	Control (n=71)	t/ χ^2	p-Value
Age (years)	9.1 ± 0.6	9.0 ± 0.5	1.12	0.26
Sex (M/F)	38/34	37/34	0.02	0.89
Height (cm)	138.5 ± 5.8	139.0 ± 6.1	-0.63	0.53
Weight (kg)	34.2 ± 6.3	33.7 ± 5.9	0.57	0.57
BMI (kg/m^2)	17.8 ± 2.5	17.5 ± 2.6	0.69	0.49

3.2. Descriptive Statistics and Intervention Effects

3.2.1. Fundamental Motor Skills (TGMD-3)

Table 2 and Figure 1 and 2 display the pre- and post-intervention scores from the TGMD-3, focusing on locomotor and object-control skills. The results

indicate that the intervention group experienced significant enhancements in both skill areas, evidenced by large effect sizes ($\eta^2 > 0.40$). In contrast, the control group exhibited only minimal changes that were not statistically significant.

Table 2. TGMD-3 Scores Pre- and Post-Intervention.

Skill Domain	Group	Pre-test Mean ± SD	Post-test Mean ± SD	ΔMean	p-Value	η^2
Locomotor	Intervention	28.6 ± 4.2	35.1 ± 4.0	+6.5	<0.001	0.42
	Control	28.4 ± 4.0	29.1 ± 4.2	+0.7	0.21	0.01
Object-Control	Intervention	26.8 ± 5.0	34.3 ± 4.5	+7.5	<0.001	0.45
	Control	27.0 ± 4.7	27.6 ± 4.8	+0.6	0.28	0.01

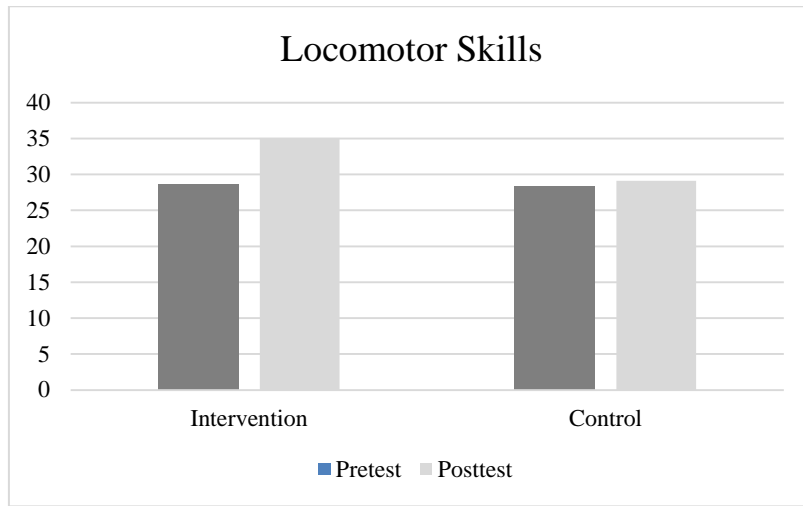


Figure 1. Mean Score of Locomotor skills across Groups and Tests

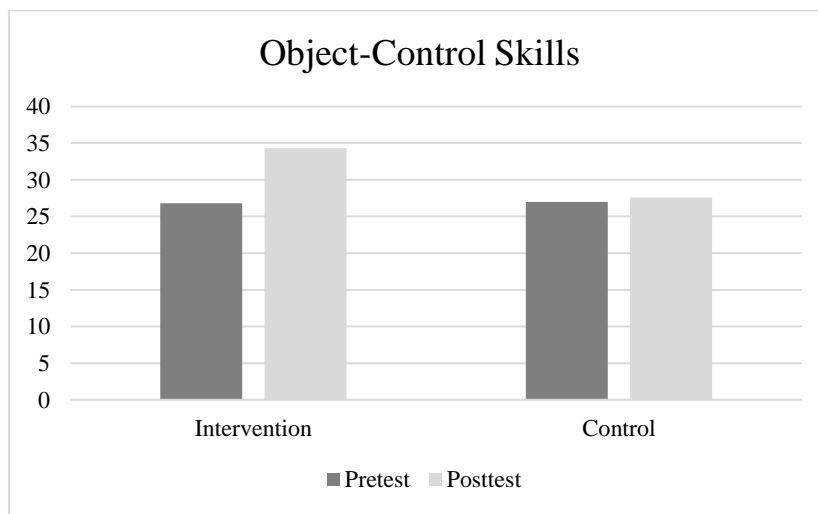


Figure 2. Mean Score of Object-Control Skills across Groups and Tests

3.2.2. Motor Competence (BOT-2 Short Form)

The intervention group demonstrated significant improvements in overall motor skills when compared to the control group (Table 3 and Figure 3).

Group	Pre-test Mean ± SD	Post-test Mean ± SD	ΔMean	p-Value	η ²
Intervention	45.2 ± 6.8	53.1 ± 6.5	+7.9	<0.001	0.38
Control	44.9 ± 6.5	46.0 ± 6.7	+1.1	0.12	0.02

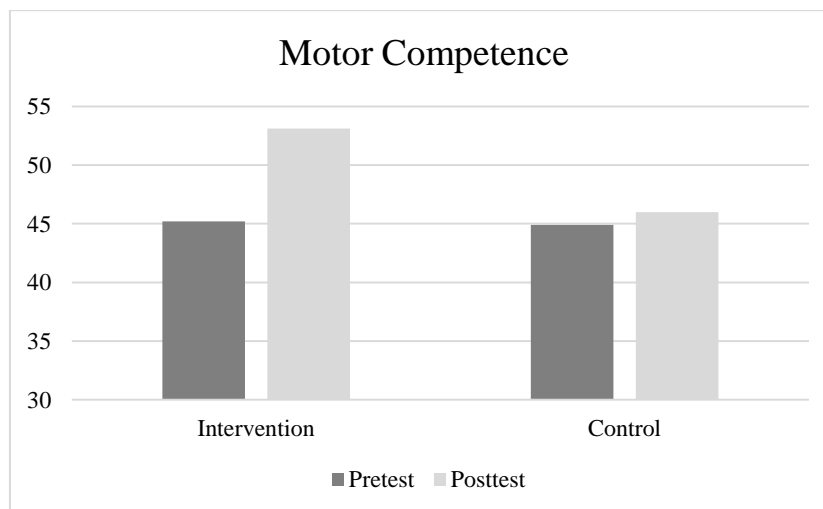


Figure 3. Mean Score of Motor Competence across Groups and Tests

3.2.3. Physical Activity (Accelerometry)

The intervention led to a significant increase in daily engagement in MVPA (Table 4 and Figure 4).

Table 4. Average Daily MVPA (minutes).

Group	Pre-test Mean \pm SD	Post-test Mean \pm SD	Δ Mean	p-Value	η^2
Intervention	34.5 \pm 12.1	52.3 \pm 14.2	+17.8	<0.001	0.36
Control	33.9 \pm 11.8	35.2 \pm 12.0	+1.3	0.22	0.01

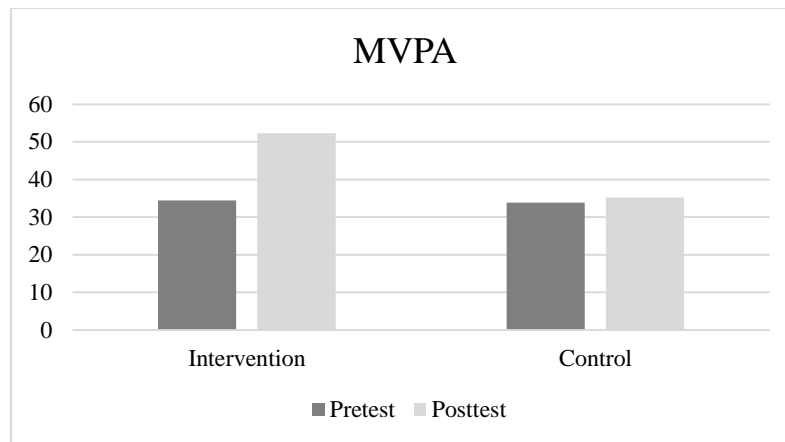


Figure 4. Mean Score of MVPA across Groups and Tests

3.3. Path Analysis

A path analysis model was employed to investigate the relationships between the intervention as the independent variable, TGMD-3 locomotor and object-control scores along with MVPA as mediators, and overall motor competence measured by BOT-2 as the dependent variable. The final model exhibited strong fit indices, including a CFI of 0.95, TLI of 0.94, RMSEA of 0.05, and SRMR of 0.04. Key findings revealed significant standardized β coefficients, indicating that the intervention positively influenced both TGMD-3 locomotor skills ($\beta = 0.62$, $p < .001$) and object-control skills ($\beta = 0.64$, $p < .001$). Furthermore, TGMD-3 locomotor skills ($\beta = 0.41$, $p < .001$) and object-control skills ($\beta = 0.38$, $p < .001$) were found to significantly predict MVPA, which in turn was associated with BOT-2 motor competence ($\beta = 0.46$, $p < .001$). Direct paths from TGMD-3 skills to BOT-2 also showed significant effects ($\beta = 0.35$ – 0.40 , $p < .001$). Notably, the indirect effect of the intervention through TGMD-3 and MVPA on BOT-2 was significant ($\beta = 0.29$, 95% CI [0.18, 0.42], $p < .001$), suggesting that PA partially mediates the relationship between FMS improvements and overall motor competence, thereby supporting the proposed mechanistic pathway.

4. Discussion

This study investigated the impact of a 12-week combined intervention of object-control and aerobic circuit training on the proficiency of FMS, PA levels, and overall motor competence in primary-school children. Employing a path-analysis methodology, we explored both direct and indirect pathways through which structured skill and aerobic training could enhance children's motor development. The findings indicated significant improvements in FMS, PA, and motor competence among the intervention group compared to the control group. Path analysis further revealed that PA served as a partial mediator in the relationship between skill proficiency and motor competence. These results offer valuable insights into the

developmental and behavioral mechanisms that connect structured motor interventions to comprehensive child health and movement competence.

The results of the intervention were in line with our expectations, demonstrating significant improvements in both locomotor and object-control skills among participants. Children in the intervention group experienced an average increase of 6.5 points in their TGMD-3 locomotor scores and 7.5 points in object-control scores, whereas the control group exhibited only minor changes. These outcomes support existing literature that highlights the effectiveness of structured, skill-specific practice, particularly in object-control activities like throwing, catching, and kicking (29,30). The integration of aerobic circuit components alongside object-control drills likely enhanced skill acquisition by fostering coordination, endurance, and engagement, thereby creating a rich learning environment conducive to motor development. The significance of these improvements is underscored by the participants' ages (8–10 years), a crucial period for motor skill advancement when children are especially receptive to structured interventions (31). By offering repeated, enjoyable practice opportunities for both locomotor and object-control tasks, the intervention effectively leveraged principles of neuroplasticity and motor learning, such as repetition, variability, and feedback, which are vital for solidifying motor patterns.

Children participating in the intervention group exhibited notable enhancements in overall motor competence, as indicated by the BOT-2 assessment, with an average increase of 7.9 points. This improvement suggests that structured skill and aerobic training not only refine specific motor abilities but also foster broader aspects of coordination, balance, strength, and agility. Such findings align with the perspective that proficiency in FMS is essential for overall motor competence (32,33). Consequently, interventions that address both skill-specific and general movement capabilities can provide extensive benefits. These results highlight the necessity of

incorporating multicomponent motor programs into school curricula. Unlike traditional physical education classes that often focus on games or general activities, structured interventions that merge skill development with aerobic training appear to be more effective in enhancing overall motor competence. This strategy may have lasting effects on children's physical literacy, as motor competence is a vital factor influencing ongoing participation in PA and the establishment of lifelong health habits (4).

Accelerometer data indicated a notable increase in MVPA among participants in the intervention group, with an average rise of 17.8 minutes per day, while the control group exhibited only slight variations. This outcome supports earlier research suggesting that structured motor skill programs can effectively boost children's spontaneous PA during and beyond the intervention sessions (34,35). Enhanced FMS likely fostered greater confidence and perceived competence in children, which in turn may have spurred increased engagement in both active play and organized activities, in line with Stodden et al.'s (2008) model that connects motor competence, self-efficacy, and PA (32,33). Additionally, the aerobic elements of the intervention probably played a role in elevating MVPA by improving endurance, cardiovascular health, and enjoyment of PA. Incorporating circuit-based aerobic exercises alongside skill development may have also encouraged children to be more active during recess, after school, and in extracurricular settings. These results imply that interventions focusing on both skill enhancement and fitness can produce complementary effects on children's overall activity levels.

The path analysis reveals a detailed understanding of the intervention's impact on motor competence. The direct effects show that enhancements in locomotor and object-control skills are strong predictors of overall motor competence. Notably, MVPA acts as a partial mediator, indicating that the intervention not only directly improved skills but also indirectly boosted motor competence by fostering greater engagement in PA. This finding supports the concept of a dynamic interplay between skill proficiency, PA, and motor development, where enhanced skills promote activity, which in turn reinforces motor competence (19,36). The mediating influence of PA highlights the significance of behavioral and motivational aspects in motor development. Children who feel adept at fundamental skills are more inclined to engage in various PA, thereby strengthening their coordination, strength, and cardiovascular fitness. This underscores the necessity for interventions that simultaneously target skill development and behavioral engagement, rather than concentrating solely on one aspect.

This study builds on previous findings that highlight the effectiveness of object-control training and aerobic exercise as standalone interventions (37,38). Unlike earlier research, which focused on these components individually, this investigation is one of the first to explore a combined, multicomponent approach and assess both direct and indirect effects through path analysis. This methodology provides a deeper insight into how such interventions impact proximal outcomes, like FMS, as well as distal outcomes, including overall motor competence and PA levels. By reflecting the varied demands of daily PA, multicomponent interventions may offer enhanced ecological validity and more significant developmental advantages compared to single-component programs.

The research outcomes present several actionable insights for educators, coaches, and policymakers. Firstly, incorporating structured object-control and aerobic circuits into physical education curricula can significantly enhance skill acquisition and motor competence among students. Additionally, focusing on children aged 8 to 10, a pivotal stage for developing physical skills, can yield substantial long-term advantages in physical literacy. Furthermore, merging skill instruction with enjoyable, high-intensity aerobic exercises may not only boost children's MVPA levels but also cultivate a more positive attitude towards PA. Lastly, utilizing objective tools like accelerometers in conjunction with validated FMS assessments can provide a comprehensive understanding of the effectiveness of these interventions.

Several limitations must be acknowledged in this study. Firstly, while participants were randomly assigned to groups, the quasi-experimental design within a school context may restrict the applicability of the findings to broader populations. Secondly, the 12-week intervention sheds light on short-term outcomes, yet further research is necessary to evaluate the long-term sustainability of the skills and activities gained. Thirdly, although accelerometers provide objective data on PA, they fall short in capturing contextual elements or qualitative dimensions of movement, such as social interaction and enjoyment. Additionally, the study's focus on typically developing children limits the generalizability of the results to those with developmental delays or physical disabilities. Future investigations should consider longer intervention durations with follow-up assessments, explore dose-response relationships, and assess psychosocial factors like self-efficacy and motivation. Moreover, incorporating technology-driven feedback, such as gamified skill challenges, could potentially boost engagement and adherence, thereby enhancing the observed benefits.

4.1. Conclusion

The current research presents strong evidence that a 12-week intervention combining object-control and aerobic circuit training significantly enhances FMS, PA levels, and overall motor competence among primary-school children. Path analysis indicates that PA serves as a partial mediator in the relationship between skill proficiency and motor competence, underscoring the complex interplay between motor development and behavioral patterns. These results advocate for the adoption of structured, multicomponent motor programs within educational environments to foster physical literacy, encourage lifelong PA, and support comprehensive child development. Incorporating such initiatives into educational policies and practices is crucial for countering the global decline in PA and improving children's motor skills and health outcomes.

Acknowledgments

The authors is grateful to all the participants who participated in this research.

Footnotes

Authors' Contribution: This study was carried out solely

by the corresponding author.

Conflicts of Interest

Non to declare.

Data Availability: The data that support the findings of this study are openly available upon request from the corresponding author.

Ethical Approval: The author confirms that all steps and requirements of this study comply with ethical guidelines. Participants were informed about the characteristics of the study and gave written informed consent.

Funding Support

This study received no grant.

Informed Consent: Informed written consent was obtained from all participants

Supplementary information accompanies this paper at doi: 10.22034/pach.2025.560762.1079

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