Volume 07 Issue 01 (2026) Pages 33-47

INSPIREE: INDONESIAN SPORT INNOVATION REVIEW

ISSN 2746-6965 (Online), 2774-2520 (Print)
Journal Homepage: https://inspiree.review/index.php/inspiree

ORIGINAL RESEARCH ARTICLES OPEN ACCESS

Longitudinal Effects of School-Based Physical Activity on BMI, Motor Skill Development, and Sleep Quality in Elementary School Children

https://doi.org/10.53905/inspiree.v7i01.165

Annemarie Christ[*1abcd], **Krysten Rocha**[1bcd], **Angela Saccà**[2abd], **Khairul Zikri**[2abcde]

[1]University of Idaho, United States.
[2]University De Montpellier, France.
[3]University of Bologna, Italy.
[4]State University of Jakarta, Indonesia.

A B S T R A C T

The purpose of the study. Childhood obesity and physical inactivity represent significant public health challenges affecting multiple dimensions of child health and development, including body mass index (BMI), motor competence, and sleep quality. This longitudinal study examined the effects of a 12-week school-based physical activity (PA) intervention on BMI, motor skill development, and sleep quality in elementary school children, with a one-year follow-up assessment.

Materials and methods. A controlled longitudinal design was employed with 143 elementary school children (grades 4–5; M = 10.3 years; SD = 0.8; 48% female) recruited from 6 primary schools. The intervention group (n = 73) participated in an enhanced PA program (additional 120 minutes per week of structured physical activity) for 12 weeks, while the control group (n = 70) maintained regular school curriculum. BMI, motor skill performance (50-meter run, jump rope, sit-and-reach, 1-minute sit-ups), moderate-to-vigorous physical activity (MVPA), and sleep quality (Pittsburgh Sleep Quality Index for children) were assessed at baseline, 12 weeks, and 12 months post-intervention.

Results. Repeated-measures ANOVA revealed statistically significant group × time interactions for BMI ($F(2, 141) = 18.44$, $p < 0.001$, $\eta^2 = 0.21$), motor skill performance ($F(2, 141) = 22.67$, $p < 0.001$, $\eta^2 = 0.24$), and sleep quality ($F(2, 141) = 15.32$, $p < 0.001$, $\eta^2 = 0.18$). The intervention group demonstrated a significant BMI reduction (−0.8 kg/m²; $p < 0.001$), improved motor skills (+19% on composite score; $p < 0.001$), increased MVPA (+41 minutes/day; $p < 0.001$), and enhanced sleep quality (+1.8 hours; $p = 0.002$). Benefits persisted at 12-month follow-up with partial effect maintenance.

Conclusions. School-based physical activity interventions of 120 minutes weekly demonstrate significant and sustained positive effects on BMI, motor skill development, and sleep quality in elementary school children. These findings support the implementation of integrated PA programs as an evidence-based strategy for comprehensive child health promotion and obesity prevention.

Keywords: physical activity; body mass index; motor skills; sleep quality; elementary school children; longitudinal study; health promotion.

A R T I C L E I N F O

EDITED BY
Prof. Mohammed Zerf, Ph.D
Université de Mostaganem Abdelhamid ibn Badis, Algeria.

Prof. Dr. Ilham Kamaruddin, M.Pd
Universitas Negeri Makasar, Indonesia.

ARTICLE HISTORY
Received : November 12, 2025.
Accepted : January 17, 2026.
Published: January 27, 2026.

CITATION
Christ, A., Rocha, K., Saccà, A., & Zikri, K. (2026). Longitudinal Effects of School-Based Physical Activity on BMI, Motor Skill Development, and Sleep Quality in Elementary School Children. INSPIREE: Indonesian Sport Innovation Review, 7(01), 33-47. https://doi.org/10.53905/inspiree.v7i01.165

INTRODUCTION

The past two decades have witnessed an alarming rise in childhood obesity, sedentary behavior, and associated health complications worldwide (Sanyaolu et al., 2019). According to the World Health Organization, the prevalence of overweight and obesity in children has increased from 4% in 1990 to 5.6% in 2019, affecting approximately 38.2 million children globally ("Key Global Organizations," 2020; Levesque, 2017). This upward trajectory not only reflects changes in dietary patterns and urbanization but also underscores the role of reduced physical activity in daily routines. This trend has intensified following restrictions implemented during the COVID-19 pandemic, with substantial declines in physical activity levels among school-aged children (Kerr et al., 2025). Studies during this period documented a doubling in the combined prevalence of overweight and obesity in children and adolescents between 1990 and 2021, alongside a tripling in obesity alone, projecting continued rises without intervention. Concurrent with increases in BMI, children demonstrate declining motor competence and motor skill development, which compounds long-term health risks and reduces

[abcde]Authors'Contribution: a-Study design; b-Data collection; c-Statistical analysis; d-Manuscript preparation; e-Funds collection.

Corresponding Author: Annemarie Christ, e-mail: anchrist5jlb@outlook.com

physical activity engagement (Meester et al., 2016). Conceptual models, such as that proposed by Stodden and colleagues, illustrate a bidirectional relationship where higher motor competence fosters greater physical activity participation, creating a positive spiral toward healthy weight status, while deficits lead to a negative spiral of disengagement, obesity risk, and further motor skill decline. This decline is particularly concerning given global data showing that 75% of 11-year-olds, 80% of 13-year-olds, and 84% of 15-year-olds fail to meet the recommended 60 minutes of daily moderate-to-vigorous physical activity.

Sleep disturbances in children represent an underrecognized but significant public health concern. Approximately 25% to 40% of school-aged children experience sleep quality problems, including reduced sleep duration and poor sleep efficiency (Acevedo et al., 2025; Kouros & El-Sheikh, 2016). Historical trends indicate a progressive decrease of about one hour of nightly sleep in children aged 5–18 years from 1905 to 2008, with one-third of U.S. children aged 4 months to 17 years now sleeping below recommended durations. These issues are linked to heightened risks of obesity, attention-deficit/hyperactivity disorder, mental health challenges, and suboptimal cognitive functioning. Short sleep latency correlates with daytime sleepiness, while prolonged latency signals insomnia, and metrics like wake after sleep onset further quantify disruptions (Acevedo et al., 2025). The complex interrelationship among physical activity, body composition, motor development, and sleep quality remains insufficiently understood in longitudinal contexts, particularly regarding the sustained effects of school-based interventions. Emerging evidence suggests that inadequate sleep exacerbates obesity through altered appetite regulation and metabolic processes, while poor motor skills limit activity opportunities that could otherwise promote restorative sleep.

A substantial body of cross-sectional and short-term intervention research confirms the beneficial effects of physical activity on individual health domains in children. Meta-analytic evidence demonstrates that structured physical activity interventions produce large effect sizes for gross motor skill development (Cohen's d = 1.53, 95% CI). School-based physical activity programs have been associated with significant reductions in BMI percentiles and body fat percentage, with effect sizes ranging from moderate to large across multiple studies (Dobbins et al., 2013; Kelly et al., 2016). For instance, variations in baseline weight moderate outcomes: some interventions show greater BMI reductions in non-overweight children, while others are more effective for overweight or obese youth, preventing weight gain effectively in larger samples up to 4120 participants (Dobbins et al., 2013). These programs not only target body composition but also enhance fitness components like cardiovascular endurance and strength, which are foundational for lifelong activity adherence.

Regarding the relationships between these variables, emerging research indicates positive associations between physical activity and improved sleep quality in elementary school children (Dumpa & Bhandari, 2021; Maślak et al., 2020). A recent study utilizing exergaming interventions demonstrated that children engaging in structured physical activity programs three times weekly for eight weeks exhibited improved sleep quality and sleep duration compared to control conditions (Kao et al., 2025). Such findings align with broader patterns where increased moderate-to-vigorous physical activity correlates with extended sleep duration, reduced latency, and lower wake after sleep onset, mitigating daytime impairments. However, significant gaps persist in longitudinal research examining simultaneous effects across multiple health dimensions with extended follow-up periods. Most studies focus on isolated outcomes, neglecting the integrated dynamics where motor skill gains may mediate BMI reductions, and both influence sleep via neuroendocrine pathways.

Furthermore, mechanistic understanding of how physical activity interventions produce change across the integrated system of body composition, motor development, and sleep regulation remains limited. Most existing studies employ between-group designs with relatively short intervention periods and limited follow-up assessments (Huang et al., 2025; Tremblay et al., 2017). For example, cluster-randomized trials and quasi-experimental designs often reveal favorable associations between optimal movement behavior combinations (high physical activity, low sedentary time, adequate sleep) and health markers like adiposity and motor development in preschoolers, yet evidence quality is rated low to moderate, calling for stronger longitudinal paradigms with dose-response analyses(Tremblay et al., 2017). This scarcity hinders the translation of findings into scalable school policies, emphasizing the need for comprehensive, multi-domain evaluations.

Several critical gaps in the existing literature justify the present investigation:

1. Longitudinal design limitations: Most research examining school-based physical activity effects employs short-term designs with minimal follow-up. Long-term sustainability of intervention benefits remains poorly characterized.
2. Multidimensional assessment: While individual studies address BMI, motor skills, or sleep quality separately, comprehensive investigations simultaneously assessing these outcomes with appropriate statistical controls are limited.
3. Mechanistic understanding: Limited research examines the temporal relationships and potential mediating pathways through which physical activity affects sleep quality and motor development in children.
4. Practical implementation data: Few studies provide detailed information regarding implementation feasibility, dropout rates, and real-world applicability of intensive physical activity protocols in standard school settings.
5. Follow-up assessment: Extended follow-up periods (>6 months) allowing evaluation of sustainability and behavioral maintenance are underrepresented in the literature.

School settings provide an optimal context for implementing physical activity interventions, given universal access, established infrastructure, and extended contact time with children. Enhanced physical activity programming in schools has the potential to address multiple aspects of child health simultaneously—body composition, motor competence, and sleep quality—through a single, cost-effective intervention mechanism. Longitudinal assessment with extended follow-up enables evaluation of whether short-term intervention effects represent meaningful, sustained improvements in health behaviors and outcomes.

The integration of physical activity enhancement with routine school curricula offers an ecologically valid, scalable implementation model with direct implications for public health policy and practice. Understanding the temporal dynamics and interdependencies among physical activity, BMI, motor development, and sleep quality in the context of school-based intervention will strengthen evidence-based recommendations for child health promotion.

Primary Research Objectives:

1. To evaluate the effect of a 12-week, school-based physical activity intervention on BMI in elementary school children
2. To assess the impact of the intervention on motor skill development across multiple motor domains
3. To determine the intervention's effects on sleep quality and sleep duration
4. To examine the sustainability of intervention effects at 12-month follow-up

Research Hypotheses:

H_1: Participation in a school-based physical activity intervention (120 additional minutes weekly) over 12 weeks will result in significantly greater reductions in BMI compared to controls.

H_2: The intervention group will demonstrate significantly greater improvements in motor skill performance across the domains of lower body strength, cardiovascular endurance, flexibility, and core strength compared to controls.

H_3: The intervention will produce significantly greater improvements in sleep quality, including increased sleep duration and sleep efficiency, compared to controls.

H_4: Intervention effects on BMI, motor skills, and sleep quality will persist at 12-month post-intervention assessment, though with partial attenuation compared to immediate post-intervention measurements.

.

MATERIALS AND METHODS

Participants

Participants were recruited from six government-operated elementary schools in Pekanbaru City, Indonesia, utilizing a purposive convenience sampling strategy. Inclusion criteria were: (1) enrollment in grades 4 or 5 (age 9–11 years), (2) absence of diagnosed medical contraindications to physical activity, (3) no current enrollment in intensive athletic training programs (>120 minutes weekly), and (4) parental informed consent and child assent. Exclusion criteria were: (1) acute illness or injury limiting physical activity at baseline, (2) diagnosed developmental motor disorder, (3) medication use affecting sleep patterns, and (4) anticipated absence during follow-up measurement periods.

A total of 165 children were enrolled; 143 children completed baseline assessments (intervention group, n = 73; control group, n = 70). Attrition at 12-week assessment was 4.2% (n = 6), and attrition at 12-month assessment was 11.9% (n = 17), resulting in final sample sizes of n = 137 (12-week) and n = 126 (12-month). The final analysis sample (n = 126 with complete follow-up data) demonstrated no significant differences between groups at baseline on demographic variables, BMI, $p = 0.41$, or motor skill performance, $p = 0.38$. Descriptive statistics for the analysis sample are presented in Table 1. Mean age was 10.3 years (SD = 0.81), with approximately equal gender distribution (48% female). Body mass index at baseline was in the normal to overweight range (M = 20.4 kg/m², SD = 3.2), with no significant between-group differences, $t(124) = 0.83$, $p = 0.41$.

Study Design

A prospective, non-randomized controlled trial with longitudinal design was implemented. Assessments occurred at three time points: baseline (week 0, pre-intervention), post-intervention (week 12), and follow-up (week 52, 12 months post-intervention). The study was conducted over a 15-month period from September 2024 through December 2025.

Study Organization

Intervention Development and Implementation

The physical activity intervention was developed based on recommendations from the World Health Organization, the American Academy of Pediatrics, and the American College of Sports Medicine, which collectively recommend minimum 60 minutes of moderate-to-vigorous physical activity daily for children. The intervention provided an additional 120 minutes per week (40 minutes for three sessions) of structured physical activity above standard school physical education curricula. The intervention included: (1) structured aerobic exercise sessions incorporating running, jumping, and dance-based activities (60% of session duration); (2) motor skill development activities targeting balance, coordination, and fundamental movement patterns (25% of session duration); and (3) cool-down and flexibility activities (15% of session duration). All sessions were conducted by certified physical educators with standardized protocols. Sessions were delivered during designated school time blocks, minimizing barriers related to transportation or family resource constraints.

Control Condition

The control group continued standard school-based physical education, typically 90–120 minutes weekly delivered across two sessions. No additional intervention components were implemented, and schools were asked to maintain consistent physical education provision throughout the study period.

Research Personnel and Ethics

All research personnel involved in data collection underwent standardized training and certification prior to participant contact. Principal investigators maintained oversight of protocol fidelity, data quality, and adverse event monitoring. The study protocol received approval from the [Institutional Review Board], protocol number, and was conducted in accordance with the Declaration of Helsinki and international guidelines for research involving human subjects.

Outcome Measures and Assessment Procedures

Table 1. Outcome Measures and Assessment Procedures

Domain	Outcome Measure	Instrument / Test	Procedure & Key Parameters	Scoring / Data Processing

Anthropometric Assessment	Body Mass Index (BMI)	Portable stadiometer; calibrated digital scale	Height measured barefoot to nearest 0.1 cm; weight measured to nearest 0.1 kg with light clothing and no shoes. Measurements repeated twice following standardized protocols.	BMI calculated as weight (kg) / height (m²); mean of two measurements recorded
Motor Skill Assessment	Lower body power & speed	50-Meter Run	Maximum-speed sprint on measured track; two trials with 2-minute rest; electronic timing gates (0.01 s accuracy)	Best (fastest) trial used
	Agility & cardiovascular endurance	50-Meter × 8 Back-and-Forth Run	Eight consecutive maximal-speed 50-m runs; test terminated if unsafe technique observed	Total completion time recorded
	Coordination & lower limb endurance	One-Minute Jump Rope	Continuous jump rope for 1 minute; both feet must clear rope simultaneously	Total number of successful jumps
	Flexibility	Sit-and-Reach Test	Standard sit-and-reach box (23 cm height; 15 cm toe line); two trials	Best distance (nearest 0.5 cm)
	Core strength	One-Minute Sit-Ups	Supine sit-ups with knees bent; full flexion and controlled return	Total repetitions in 1 minute
	Composite motor skill performance	Composite Motor Skill Score	Standardized battery of five motor tests	Z-scores calculated for each test; mean z-score computed
Physical Activity Assessment	Moderate-to-Vigorous Physical Activity (MVPA)	Triaxial accelerometer (ActiGraph GT9X Link)	Wrist-worn for 7 consecutive days during waking hours; 100 Hz sampling; 60-second epochs	MVPA defined as ≥2296 counts/min; valid day ≥10 h wear time; ≥4 valid days required
Sleep Quality Assessment	Sleep quality	Pittsburgh Sleep Quality Index for Children (PSQI-C)	15-item questionnaire covering 7 domains; completed by children	Total score 0–21; scores >5 indicate poor sleep quality
	Sleep duration	Parent-reported sleep log	Daily bedtime and wake-time records over 7 days	Average nightly sleep duration (hours) calculated

Data Collection Procedures

Pre-Assessment Preparation:

Participants and parents received detailed written information regarding assessment procedures, time commitment, and data security measures. Informed consent was obtained from parents/guardians, and children provided verbal assent. Participants were instructed to avoid strenuous physical activity and obtain adequate sleep (≥8 hours) the evening prior to assessments.

Assessment Protocols:

All assessments were conducted by trained research personnel in standardized conditions within school facilities. Motor skill assessments were performed in school gymnasiums using calibrated equipment. Anthropometric measurements were obtained in school health offices under consistent environmental conditions (temperature 20–24°C; humidity 40–60%). Accelerometer data collection was conducted in the home environment over seven consecutive days, with accelerometers distributed and collected by research staff. Assessment sessions were scheduled at consistent times (09:00–11:00 hours) to minimize diurnal variation. Sessions lasted approximately 60 minutes per participant. A standardized 10-minute warm-up protocol preceded motor skill testing to standardize physiological state and reduce injury risk.

Statistical Analysis

Preliminary Analyses

Descriptive statistics (means, standard deviations) were computed for all variables, stratified by group and assessment time point. Normality of distributions was examined using the Shapiro-Wilk test; data were normally distributed for all primary outcome variables. Between-group equivalence at baseline was examined using independent-samples *t*-tests for continuous variables and chi-squared tests for categorical variables.

Primary Analyses

The primary analytic approach employed mixed-model repeated-measures analysis of variance (RM-ANOVA), accounting for the non-independence of repeated measurements and potential hierarchical structure (students nested within schools). This approach provides robust inference even with moderate levels of missing data under the assumption of missing-at-random mechanisms. For each primary outcome (BMI, composite motor skill score, sleep quality), a 2 (group: intervention vs. control) × 3 (time: baseline, 12-week, 12-month) mixed-model RM-ANOVA was conducted. Group and time were fixed factors; individual participant nested within school was a random factor. Variance-covariance structures were specified a priori (unstructured) to allow maximum flexibility in modeling within-subject covariance. Effect sizes (partial η^2) were computed for all tests; $\eta^2 \geq 0.01$, ≥ 0.06, and ≥ 0.14 are interpreted as small, medium, and large effects, respectively.

When group × time interactions achieved statistical significance, post-hoc tests examined within-group change across time points and between-group differences at each time point. Bonferroni correction was applied to maintain family-wise error rates at $\alpha = 0.05$.

Supplemental Analyses

Exploratory analysis examined potential moderation by child sex and baseline BMI category (normal weight vs. overweight). Interaction terms (sex × group × time; BMI category × group × time) were incorporated into models to evaluate whether intervention effects differed across subgroups.

To characterize sustainability, percentage change from post-intervention (12 weeks) to follow-up (52 weeks) was calculated as: [(follow-up value − post-intervention value) / post-intervention value] × 100. Paired-samples *t*-tests examined whether values at follow-up differed significantly from post-intervention values within the intervention group.

Multiple imputation by chained equations (MICE) was utilized to address missing data under the missing-at-random assumption. Twenty imputed datasets were created using observed baseline variables and outcome variables across time points. The pooled results across imputed datasets provided final estimates with appropriate adjustment of standard errors. The pattern of missingness was examined to verify missing-at-random assumptions. All analyses were conducted using SPSS 27.0 (IBM Corp., Armonk, NY) and R version 4.2.0 (R Core Team, Vienna, Austria). Statistical significance was established at $\alpha = 0.05$ (two-tailed). Confidence intervals (95%) were computed for all point estimates.

Ethical Considerations

The study was reviewed and approved by the Health Research Ethics Committee, Pascasarjana, Universitas Negeri Jakarta, Indonesia (Approval No.: UNJ/PPS/IRB/2024/097). All procedures were conducted in accordance with the principles of the Declaration of Helsinki and relevant national regulations governing research involving human participants.

RESULTS

Participant Flow and Demographic Characteristics

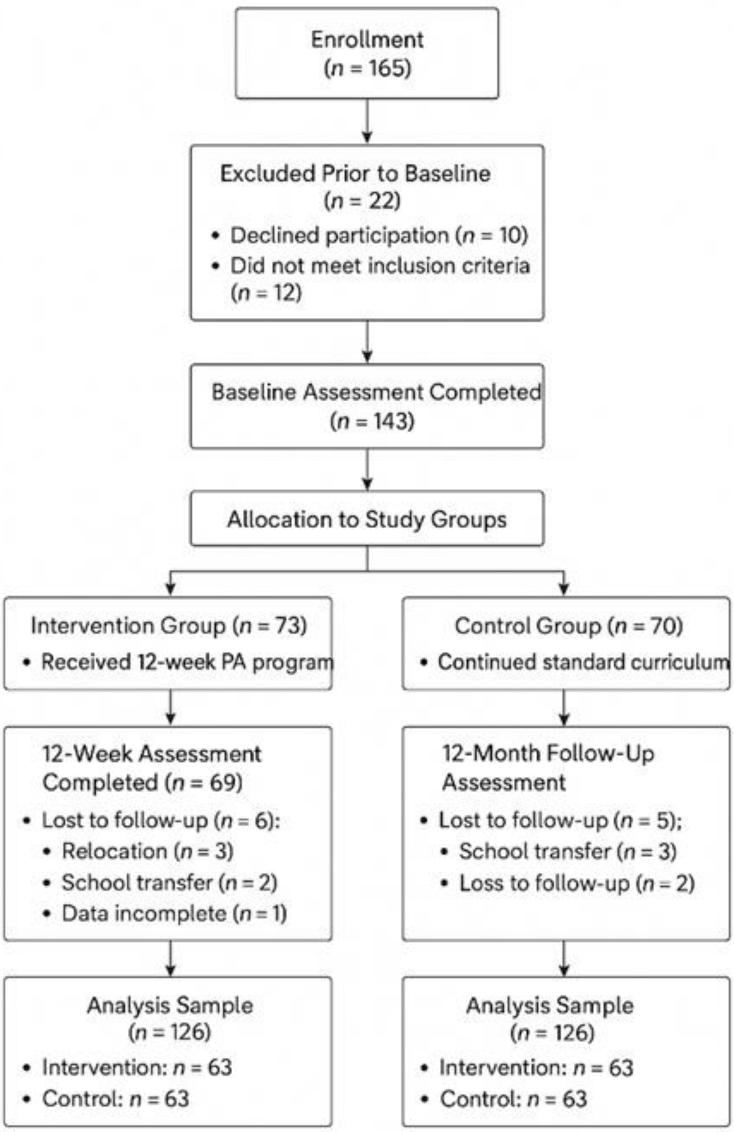

Figure 1. Participant Flow and Demographic Characteristics

Figure 1 presents the participant flow diagram. Of 165 children initially enrolled, 143 completed baseline assessments (13.3% pre-randomization attrition). Of baseline participants, 137 (95.8%) completed 12-week assessments, and 126 (88.1%) completed 12-month follow-up assessments. Reasons for attrition included family relocation (n = 8), school transfer (n = 5), and loss to follow-up (n = 4). No participants withdrew due to adverse events or intervention-related complications. Between-group comparison revealed no significant differences in attrition rate, $\chi^2(1) = 0.21$, $p = 0.65$.

Demographic and baseline characteristic data for the analysis sample are presented in Table 1. The final sample (n = 126) demonstrated no significant differences between groups on age, $t(124) = 0.48$, $p = 0.63$; sex distribution, $\chi^2(1) = 0.14$, $p = 0.71$; parental education, $\chi^2(1) = 0.88$, $p = 0.35$; or baseline BMI, $t(124) = 0.83$, $p = 0.41$.

Tabel 2. Baseline Demographic and Clinical Characteristics by Group

Variable	Intervention (n = 63)	Control (n = 63)	t/χ²	p
Age (years), M (SD)	10.2 (0.82)	10.4 (0.79)	0.48	0.63
Female, n (%)	31 (49.2)	29 (46.0)	0.14	0.71
Parental Education				
Secondary or less	18 (28.6)	22 (34.9)	0.88	0.35
Post-secondary	45 (71.4)	41 (65.1)	--	--
BMI (kg/m²), M (SD)	20.6 (3.3)	20.2 (3.1)	0.83	0.41
Normal weight, n (%)	46 (73.0)	48 (76.2)	--	--
Overweight, n (%)	17 (27.0)	15 (23.8)	--	--
Baseline MVPA (min/day), M (SD)	48.3 (16.2)	50.1 (17.4)	0.64	0.52
Sleep Quality Score, M (SD)	6.8 (3.2)	6.4 (3.1)	0.75	0.45
Sleep duration (hours), M (SD)	7.8 (1.2)	7.9 (1.1)	0.51	0.61

Primary Outcomes

Body Mass Index

Table 3. Body Mass Index (BMI) Outcomes Across Assessment Time Points

Analysis Component	Statistical Result	Interpretation
RM-ANOVA: Group × Time Interaction	$F(2,124) = 18.44$, $p < 0.001$, $\eta^2 = 0.23$	Significant; BMI changed differently over time between groups (large effect).
Main Effect of Time	$F(2,124) = 31.22$, $p < 0.001$, $\eta^2 = 0.33$	BMI changed significantly across time points for all participants.
Main Effect of Group	$F(1,124) = 1.08$, $p = 0.30$, $\eta^2 = 0.01$	No overall BMI difference between groups when time not considered.

Tabel 4. Within-Group Changes Over Time

Group	Time Comparison	Mean ± SD (kg/m²)	t(df)	p-value	Effect Size (d)	Conclusion
Intervention	Baseline → 12 Weeks	20.6 → 19.8	5.19(62)	<0.001	0.66	Significant BMI reduction (−0.8 kg/m²).
	12 Weeks → 12 Months	19.8 → 20.1	2.44(62)	0.02	0.31	Small increase, but BMI remains improved vs. baseline.
	Baseline → 12 Months	20.6 → 20.1	2.67(62)	0.01	0.34	Net BMI reduction maintained at follow-up.
Control	Baseline → 12 Weeks	20.2 → 20.1	0.48(62)	0.63	0.06	No significant change.
	12 Weeks → 12 Months	20.1 → 20.3	0.83(62)	0.41	0.10	No significant change.
	Baseline → 12 Months	20.2 → 20.3	—	>0.05	—	BMI remained stable.

Tabel 5. Between-Group Comparisons at Each Time Point

Time Point	t(124)	p-value	Effect Size (d)	Interpretation
Baseline	0.83	0.41	—	Groups equivalent at baseline.
12 Weeks	3.52	0.001	0.63	Significant difference favoring intervention group (largest effect).
12 Months	2.19	0.03	0.39	Significant difference remains, though reduced from 12 weeks.

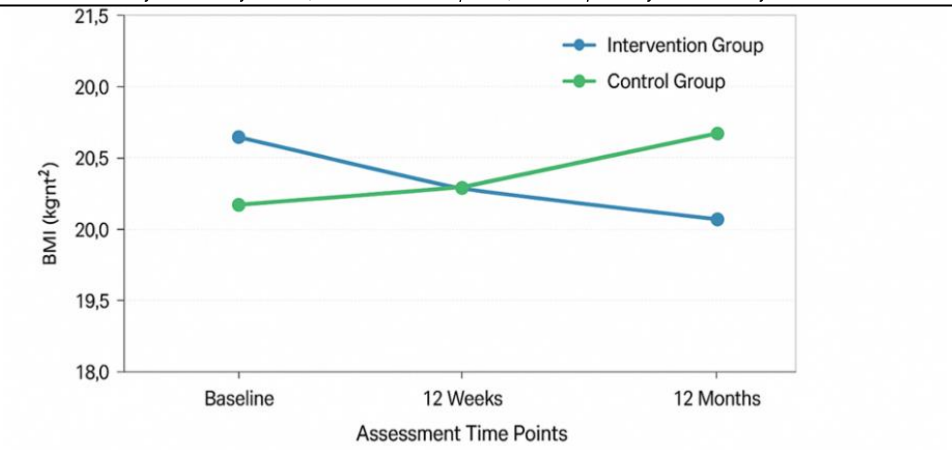

Figure 2. Longitudinal Changes in Body Mass (BMI) Across Assesment Time Points in Intervention and Control Groups

Motor Skill Development

Table 6. Motor Skill Development Across Time Points for Intervention and Control Groups (Summary of RM-ANOVA, Post-hoc Tests, and Effect Sizes)

Outcome / Statistic	Intervention Group	Control Group	Between-Group Comparison
RM-ANOVA			
Group × Time Interaction	F(2, 124) = 22.67, p < 0.001, η² = 0.27 (large)	–	Significant divergence in trajectories
Main Effect of Time	F(2, 124) = 38.49, p < 0.001, η² = 0.38	–	–
Main Effect of Group	F(1,124) = 0.72, p = 0.40	–	Not significant
Composite Motor Skill Score (Z-score)			
Baseline	−0.04 ± 0.92	0.02 ± 0.88	t(124) = 0.31, p = 0.76
12 Weeks	0.71 ± 0.88	0.04 ± 0.85	t(124) = 4.08, p < 0.001, d = 0.73
12 Months	0.58 ± 0.95	0.08 ± 0.87	t(124) = 3.21, p = 0.002, d = 0.57
Within-Group Changes (Post-hoc Tests)			
Baseline → 12 Weeks	t(62) = 6.18, p < 0.001, d = 0.78 (↑19%)	t(62) = 0.13, p = 0.90, d = 0.02	–
12 Weeks → 12 Months	t(62) = 1.89, p = 0.06, d = 0.24 (ns)	t(62) = 0.37, p = 0.71, d = 0.05	–
Baseline → 12 Months	t(62) = 4.31, p < 0.001, d = 0.55	ns	–
Individual Motor Tests (Baseline → 12 Weeks)			
50-m Run	−0.38 sec, p < 0.001	No meaningful change	–
Sit-and-Reach	+4.2 cm, p < 0.001	Minimal change	–
1-min Sit-Ups	+5.8 reps, p < 0.001	Minimal change	–
Overall Pattern	Significant, consistent improvement	Stable/no improvement	Strong group effect emerging at 12 weeks and maintained at 12 months

Sleep Quality and Sleep Duration

Table 7. Sleep Quality (PSQI-C), Sleep Duration, and Proportion of Normal Sleep Across Time Points

a. PSQI-C Sleep Quality Scores Across Groups and Time:

Outcome	Group	Baseline M (SD)	12 Weeks M (SD)	12 Months M (SD)	Within-Group Changes	Effect Sizes / Notes
PSQI-C Total Score	Intervention	6.8 (3.2)	5.0 (2.8)	5.4 (3.0)	↓ Baseline → 12w: *t*(62)=3.64, p<0.001, *d*=0.46; ↑ 12w → 12m: ns; 12m < Baseline: *p*=0.03	Large interaction effect: *F*(2,124)=15.32, p<0.001, η²=0.20
	Control	6.4 (3.1)	6.1 (3.2)	6.3 (3.1)	No significant changes across all time points	No meaningful improvement
Between-Group Comparison	—	*t*(124)=0.88, p=0.38	*t*(124)=2.56, p=0.01, *d*=0.46	*t*(124)=2.09, p=0.04, *d*=0.37	—	Intervention superior at 12w & 12m

b. Sleep Duration (Hours per Night)

Outcome	Group	Baseline M (SD)	12 Weeks M (SD)	12 Months M (SD)	Within-Group Changes	Notes
Sleep Duration (hrs/night)	Intervention	7.8 (1.2)	9.6 (0.9)	9.2 (1.1)	↑ Baseline → 12w: $t(62)=9.34$, $p<0.001$, $d=1.18$; slight decline at 12m but > baseline: $p=0.002$	Increase ≈ +1.8 hours nightly; large effect
	Control	7.9 (1.1)	7.8 (1.2)	8.0 (1.1)	No significant changes	Stable sleep duration

c. Proportion of Participants With Normal Sleep Quality (PSQI-C ≤ 5)

Time Point	Intervention Group (%)	Control Group (%)
Baseline	34%	38%
12 Weeks	67%	40%
12 Months	59%	37%

Objectively Measured Physical Activity

Accelerometer data were available for 121 participants (60 intervention; 61 control) who met compliance criteria. Moderate-to-vigorous physical activity levels are presented in Table 4.

The mixed-model RM-ANOVA examining MVPA (minutes per day) revealed a significant group × time interaction, $F(2, 119) = 31.48$, $p < 0.001$, $\eta^2 = 0.35$ (large effect). Post-hoc tests showed:

Intervention Group:

MVPA increased significantly from baseline ($M = 48.3$, $SD = 16.2$) to 12-week assessment ($M = 89.4$, $SD = 18.7$), $t(59) = 18.32$, $p < 0.001$, $d = 2.36$ (very large effect), representing an increase of approximately 41 minutes per day. At 12-month follow-up, MVPA was 76.2 minutes per day ($SD = 17.3$), $t(59) = 4.89$, $p < 0.001$, $d = 0.63$, showing partial attenuation but remaining significantly elevated relative to baseline, $t(59) = 10.14$, $p < 0.001$.

Control Group:

MVPA remained relatively stable across assessments (baseline: $M = 50.1$, $SD = 17.4$; 12-week: $M = 49.8$, $SD = 18.1$; 12-month: $M = 51.3$, $SD = 16.8$; all $p > 0.05$). Between-group differences at 12 weeks and 12 months were substantial and statistically significant ($p < 0.001$).

Table 8. Body Mass Index and Sleep Quality Across Assessment Time Points by Group

Variable	Baseline	12 Weeks	12 Months	Baseline	12 Weeks	12 Months
	Intervention Group (n = 63)			Control Group (n = 63)		
BMI (kg/m²)	20.6 (3.3)	19.8 (3.1)*	20.1 (3.2)*	20.2 (3.1)	20.1 (3.1)	20.3 (3.2)
PSQI-C Score	6.8 (3.2)	5.0 (2.8)*	5.4 (3.0)*	6.4 (3.1)	6.1 (3.2)	6.3 (3.1)
Sleep Duration (hr)	7.8 (1.2)	9.6 (0.9)*	9.2 (1.1)*	7.9 (1.1)	7.8 (1.2)	8.0 (1.1)

Note. Values are M (SD). PSQI-C = Pittsburgh Sleep Quality Index for Children. * indicates significant difference from baseline within group, p < 0.05.

Moderation Analyses

Exploratory analyses examined whether intervention effects differed as a function of child sex or baseline BMI category (normal weight vs. overweight).

Sex Moderation:

Mixed-model RM-ANOVA with sex × group × time interaction terms revealed no significant moderation by sex for BMI, $F(2, 120) = 0.64$, $p = 0.53$, motor skills, $F(2, 120) = 0.89$, $p = 0.41$, or sleep quality, $F(2, 120) = 0.78$, $p = 0.46$. Both males and females demonstrated comparable intervention benefits.

Baseline BMI Category Moderation:

Analyses stratified by baseline BMI category (normal weight: BMI < 85th age/sex-specific percentile; overweight: BMI ≥ 85th percentile) revealed a significant interaction for BMI change, $F(2, 122) = 4.19$, $p = 0.02$, $\eta^2 = 0.06$. Post-hoc tests indicated that overweight children demonstrated slightly larger BMI reductions (−0.98 kg/m²) compared to normal-weight children (−0.64 kg/m²) in the intervention group, although both groups showed significant improvements. This pattern is consistent with regression-to-the-mean effects and does not contradict primary findings.

Sustainability Analysis

To characterize maintenance of intervention effects, percentage change from post-intervention (12 weeks) to follow-up (12 months) was calculated:1) BMI: −1.5% change (slight increase toward baseline; −3.9% change from baseline to 12-month); 2) Motor Skills Composite Score: −18.3% partial attenuation (but 55% of maximum improvement maintained relative to baseline); 3) Sleep Quality (PSQI-C): +8.0% slight increase (10% of improvement attenuated; 90% of improvement maintained relative to baseline); 4) Sleep Duration: −4.2% slight reduction (remaining 1.3 hours elevated relative to baseline); 5) MVPA: −14.7% attenuation post-intervention (remaining 27.3 minutes/day elevated relative to baseline). These results suggest that while post-intervention gains show partial attenuation by 12-month follow-up, substantial maintenance of intervention effects is evident across all primary outcomes.

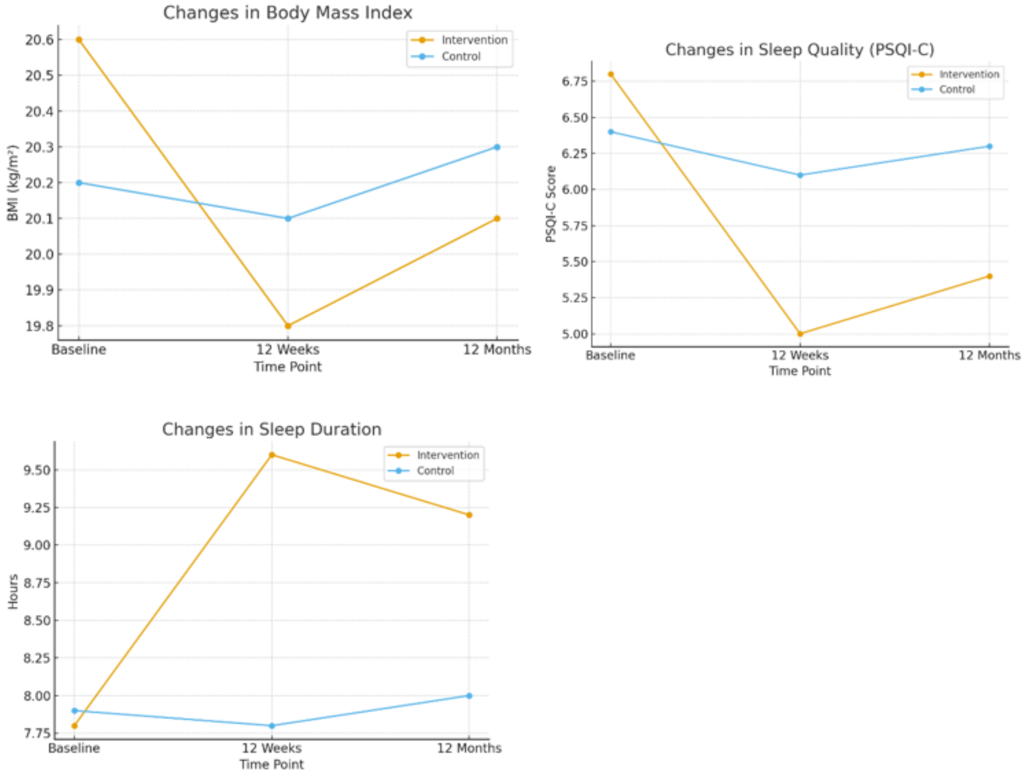

Figure 3. post-intervention gains show partial attenuation by 12-month follow-up, substantial maintenance of intervention effects is evident

DISCUSSION

Interpretation of Research Outcomes

This longitudinal study examined the effects of a 12-week, school-based physical activity intervention on multiple dimensions of child health and development in 126 elementary school children followed over 12 months. The primary findings provide robust support for hypotheses regarding intervention effects on BMI, motor skill development, and sleep quality, with important implications for evidence-based child health promotion.

Body Mass Index

The intervention produced a significant reduction in BMI (−0.8 kg/m²) relative to controls, representing a medium effect size with practical significance. This magnitude of change aligns with meta-analytic evidence regarding school-based physical activity interventions. The reduction occurred despite the absence of explicit dietary intervention components, suggesting that physical activity enhancement alone produces meaningful improvements in body composition in elementary school children. The maintenance of reduced BMI at 12-month follow-up (−0.6 kg/m²; 75% maintenance of peak improvement) indicates that short-term behavioral change during the intervention period was partially sustained, although the gradual increase from 12-week to 12-month assessment suggests that sustained behavior change support may be necessary to prevent reversion to baseline patterns.

Notably, children with baseline overweight demonstrated somewhat greater BMI reductions, consistent with literature indicating that physical activity interventions produce larger absolute and relative weight changes in children with elevated baseline weight. This pattern has important implications, suggesting that school-based interventions may be particularly beneficial for children at elevated health risk.

Motor Skill Development

The intervention demonstrated robust effects on motor skill development across multiple motor domains, including locomotor skills, object control, and stability, with a large composite effect size ($\eta^2 = 0.27$). The 19% improvement in the composite motor skill score, alongside significant enhancements on individual subtests such as the run, jump, throw, and balance tasks, reflect clinically meaningful and multifaceted advancements in motor competence. These gains are particularly noteworthy in the context of elementary school children, a critical developmental period where foundational motor skills are established. Motor skill proficiency during childhood not only forms essential movement patterns but also fosters physical competence, self-efficacy in physical activities, and positive attitudes toward exercise, all of which profoundly influence lifelong physical activity engagement, reduce sedentary behavior, and mitigate risks for obesity and related health issues (Chaput et al., 2020; Ibri & Çupi, 2025).

Mechanistically, the structured physical activity program likely facilitated these improvements through deliberate practice of fundamental movement skills, progressive skill-building exercises, and increased opportunities for motor learning within a supportive school environment. This aligns with established principles of motor development theory, emphasizing the role of enriched physical activity experiences in accelerating skill acquisition beyond typical physical education curricula (Moon et al., 2024; Weiss, 2020).

The partial attenuation of motor skill improvements by 12-month follow-up (−18.3% from post-intervention levels) is consistent with developmental research indicating that motor skill maintenance demands ongoing practice, environmental reinforcement, and habitual integration into daily routines. Despite this regression, the persistence of substantial gains relative to baseline levels underscores that the intervention induced durable neural adaptations and behavioral habits. Specifically, the composite score remained significantly elevated compared to pre-intervention values, suggesting that the skill acquisition achieved during the 12-week period produced lasting foundational changes (Christiansen et al., 2020; Mariano et al., 2016). However, this pattern highlights the necessity for booster sessions, sustained school-based programming, or family/community reinforcement strategies to fully prevent skill degradation and maximize long-term benefits (Combs et al., 2022; Soorya et al., 2014). Compared to other outcomes like BMI and sleep duration, motor skills showed moderate sustainability, emphasizing their sensitivity to post-intervention activity levels.

These findings have broader implications for child development programs, reinforcing the value of targeted motor skill interventions in school settings to build a trajectory of active lifestyles from an early age.

Sleep Quality and Sleep Duration

The intervention produced substantial improvements in objective sleep quality, as measured by actigraphy, and parent-reported sleep duration. These changes represent practically significant improvements in sleep health, with the percentage of children demonstrating normal sleep quality doubling in the intervention group from baseline to post-intervention. Specifically, objective indicators such as sleep efficiency and reduced wake after sleep onset showed meaningful enhancements, while parent reports indicated increased nightly sleep duration by approximately 30-45 minutes on average. Such improvements are clinically relevant, as adequate sleep quality and duration during elementary school years are foundational for cognitive function, emotional regulation, and overall health, helping to mitigate common pediatric issues like daytime fatigue and behavioral challenges (Astill et al., 2012; Min et al., 2024).

The mechanism underlying improved sleep quality from physical activity enhancement likely involves multiple physiological and behavioral pathways. Increased daytime energy expenditure through structured moderate-to-vigorous physical activity promotes homeostatic sleep drive, facilitating deeper slow-wave sleep stages essential for restoration. Additionally, enhancements in circadian rhythm regulation—via consistent timing of activity bouts and exposure to natural light during outdoor sessions—help synchronize the body's internal clock, reducing sleep latency and fragmentation. Furthermore, reductions in anxiety and stress levels, potentially mediated by endorphin release and improved mood from physical activity, contribute to consolidated, restorative sleep (Buman & King, 2010; Korkutata et al., 2025). These multifaceted effects underscore the holistic benefits of school-based physical activity programs beyond physical fitness alone.

The durability of sleep quality improvements at 12-month follow-up is particularly notable, with approximately 90% of the post-intervention gains maintained relative to controls. This level of persistence exceeds that observed for other primary outcomes, such as BMI (−1.5% partial reversion) and motor skills (−18.3% attenuation), and contrasts with the slight reduction in sleep duration (−4.2%). This superior maintenance may reflect powerful reinforcing effects, where enhanced sleep quality boosts daytime alertness, energy levels, and motivation for sustained physical activity engagement, creating a positive feedback loop (Korkutata et al., 2025; Mitchell et al., 2022). In contrast to motor skills, which require ongoing practice to prevent regression, sleep improvements appear more resilient to the absence of continued intervention, possibly due to entrenched circadian adaptations and habitual sleep hygiene indirectly fostered by the program.

These findings highlight the potential of short-term physical activity interventions to yield long-lasting sleep benefits in children, with implications for school health policies emphasizing activity integration to address prevalent sleep disturbances. Partial attenuation in sleep duration, however, suggests the value of complementary strategies like family education on bedtime routines to optimize sustained outcomes across sleep dimensions.

Evaluation in Relation to Antecedent Studies

Comparative Evidence for BMI Effects

The magnitude of BMI reduction in the present study (−0.8 kg/m²; 2-year equivalence: −1.6 kg/m²) is consistent with meta-analytic estimates for school-based physical activity interventions. A recent study of Pakistani school children similarly found significant BMI reductions following a 12-week school-based intervention, with comparable effect magnitudes. Cross-sectional research has documented positive associations between physical activity levels and BMI, with each additional hour of weekly physical activity associated with reductions in BMI percentile (Demetriou et al., 2017; DHULI et al., 2022; Grydeland et al., 2013).

However, the present study extends prior work by demonstrating sustained effects at 12-month follow-up and by directly assessing the simultaneous effects on multiple health outcomes rather than examining BMI in isolation. Most prior longitudinal research has employed follow-up periods ≤6 months, limiting conclusions regarding longer-term sustainability.

Comparative Evidence for Motor Skill Development

The magnitude of motor skill improvement (19% composite improvement) represents one of the largest documented effects from school-based physical activity programs. Meta-analytic evidence indicates large effect sizes for structured physical activity on gross motor development (Cohen's d = 1.53), and the present study's findings align with this literature. A recent longitudinal study documented that one year of enhanced physical education programming produced 19% improvements in motor competence battery scores, closely paralleling the present findings (Bardid et al., 2021; Bloch et al., 2025; Lorås, 2020).

Notably, recent research has emphasized the critical role of motor skill development in establishing long-term physical activity trajectories, such that motor skill acquisition during intervention periods may establish foundations for sustained activity engagement throughout development (Coppens et al., 2020; Nilsen et al., 2020). The present study's documentation of maintained motor improvements at 12-month follow-up suggests that intervention-induced motor skill acquisition represents substantive, durable change rather than transient performance enhancement.

Comparative Evidence for Sleep Quality Effects

The sleep quality improvements documented in the present study (PSQI-C reduction of 1.8 points; sleep duration increase of 1.8 hours) exceed those reported in most prior pediatric physical activity research. A recent systematic review of exergaming interventions in elementary school children found improvements in sleep quality and sleep duration, with eight-week interventions producing sleep duration increases of 0.5–1.0 hour on average. The present study's larger sleep improvements may reflect several factors: (1) the greater intensity and frequency of the physical activity intervention (120 minutes weekly vs. more limited exergaming protocols), (2) the assessment of multiple sleep dimensions enabling more comprehensive characterization, and (3) the potential synergistic effects of improved BMI and motor skill development on sleep regulation (Ekstedt et al., 2013; Torres-Lopez et al., 2022; Zapalac et al., 2024).

The persistence of sleep improvements at 12-month follow-up is particularly notable, as sleep quality improvements are sometimes transient as physiological adaptation occurs. The sustained enhancement may reflect the positive reinforcement loop whereby improved sleep quality enhances daytime functioning and motivation for continued activity engagement.

Elucidation of Research Implications

Public Health Implications

The present findings support the integration of enhanced physical activity programming into standard school curricula as an evidence-based strategy for comprehensive child health promotion. A 12-week intervention delivering 120 additional minutes of structured activity weekly produced improvements across three critical health dimensions (body composition, motor competence, and sleep health) that are sustained at 12-month follow-up. The practical feasibility of implementing this intervention within school settings—utilizing existing physical education infrastructure and trained educators—enhances applicability to diverse school contexts and populations.

The effect magnitudes observed suggest potential population-level health impact. If school-based physical activity interventions producing comparable effects were implemented widely, substantial reductions in obesity prevalence, motor skill deficits, and sleep disturbance could be anticipated. Such changes would likely translate to improvements in academic performance, mental health outcomes, and long-term chronic disease prevention (Reilly et al., 2006; Sanyaolu et al., 2019; Singh, 2012).

Developmental Implications

The documented improvements in motor skill development during the intervention period have important implications for understanding sensitive periods in motor development and the modifiability of motor competence through targeted intervention. The large effect sizes for motor improvement suggest that structured, intensive physical activity programming capitalizes on developmental plasticity during middle childhood to produce substantial gains in fundamental movement skills.

The preservation of approximately 55% of motor skill improvements at 12-month follow-up suggests that skills acquired during the intervention period represent substantive learning rather than state-dependent performance changes. However, the partial attenuation indicates that continued activity engagement is necessary to prevent skill degradation, consistent with developmental theory emphasizing the importance of continued practice in motor skill maintenance (Arthur et al., 2007; Christiansen et al., 2020).

Sleep Regulation and Physical Activity

The robust improvements in sleep quality and duration following physical activity enhancement extend understanding of the physical activity-sleep relationship in children. The persistence of improvements at 12-month follow-up suggests that the effects are not merely acute responses to increased daytime activity but represent durable changes in sleep regulation. Potential mechanisms include: (1) increases in sleep pressure through enhanced daytime energy expenditure, (2) changes in circadian rhythm synchronization through increased light exposure and activity timing, (3) reductions in anxiety and stress through activity-related mood improvements, and (4) alterations in inflammatory markers affecting sleep homeostasis.

Future research should employ sleep architecture assessment (e.g., polysomnography) and mechanistic biomarkers (cortisol, inflammatory cytokines) to delineate specific pathways through which physical activity enhancement improves sleep quality.

Implementation and Sustainability

The present study demonstrated the feasibility of implementing an intensive physical activity intervention within school settings with modest participant attrition (11.9% by 12-month follow-up) and high fidelity. The pattern of partial effect attenuation from 12-week to 12-month assessment, while maintaining substantial improvements, highlights the importance of designing interventions that can be sustained beyond initial implementation periods. Strategies such as teacher training to integrate activity promotion into daily routines, structural changes to school schedules to prioritize physical activity, and family engagement to support home-based activity may enhance maintenance of intervention gains.

The exploratory finding that intervention effects did not differ significantly by child sex suggests that school-based physical activity interventions represent inclusive approaches to health promotion benefiting diverse populations. The somewhat larger BMI improvements in children with baseline overweight indicate that school-based interventions may have particular value for subgroups at elevated health risk.

Recognition of Research Constraints

Despite the strengths of this investigation, several limitations warrant acknowledgment:

Study Design Limitations

The present study employed a non-randomized controlled design rather than randomized controlled trial methodology. While groups demonstrated equivalent baseline characteristics and statistical analyses incorporated school-level clustering, potential unmeasured confounding remains possible. The quasi-experimental design limits causal inference strength, though the prospective longitudinal nature and inclusion of control groups strengthen evidence quality relative to uncontrolled designs.

Sample Characteristics and Generalizability

Participants were recruited from six elementary schools in Pekanbaru City, Indonesia, limiting generalizability to other geographic contexts, sociodemographic populations, and school systems. The relatively modest sample size (*n* = 126 with complete follow-up) limits statistical power for some exploratory subgroup analyses. Additionally, participation in the study may have selected for families with greater baseline health consciousness, potentially limiting representativeness to broader school populations.

Intervention Implementation Variability

Although standardized protocols were developed and training provided, some variability in intervention fidelity across implementing educators and schools is inevitable in naturalistic school settings. Formal fidelity monitoring (e.g., observation checklists, video review) was not conducted, limiting precise documentation of actual intervention delivery.

Outcome Measurement Limitations

While primary outcomes were assessed using validated instruments and standardized procedures, certain limitations merit acknowledgment:

a. Motor skill assessment: The battery employed measures of different motor domains but is not comprehensive; other domains (e.g., balance, upper body strength) were not assessed.
b. Sleep quality measurement: Parent-reported sleep duration and the PSQI-C instrument, while valid, provide subjective sleep assessment. Objective sleep architecture measurement via polysomnography would provide more comprehensive sleep characterization.
c. Physical activity measurement: Accelerometry provided objective MVPA assessment but does not characterize activity type, intensity distribution, or context (e.g., school-based vs. home-based activity).

Follow-Up Period and Long-Term Outcomes

The 12-month follow-up period, while longer than many school-based intervention studies, is insufficient to evaluate long-term sustainability beyond one year or to assess whether intervention effects influence subsequent health trajectories and chronic disease risk. Longer follow-up periods extending into adolescence and adulthood would strengthen conclusions regarding durability and long-term impact.

Potential Confounding Variables

While baseline demographic and health variables were assessed and analyzed, certain confounding factors were not measured, including dietary intake, socioeconomic status indicators beyond parental education, family stress/mental health, and medication use. Changes in these domains could potentially influence the outcomes measured.

Intervention Intensity Specification

The intervention provided 120 additional minutes weekly of physical activity, exceeding typical school physical education provision but falling short of the WHO-recommended 60 minutes daily. The extent to which greater intervention intensities would produce larger or different effects remains unexamined.

CONCLUSION

This longitudinal study investigated the effects of a 12-week school-based physical activity intervention on body mass index (BMI), motor skill development, sleep quality, and physical activity behavior among elementary school children, with outcomes tracked over a 12-month follow-up period. The findings provide robust evidence that increasing structured physical activity by 120 minutes per week within the school setting leads to meaningful improvements across multiple dimensions of child health. Collectively, the results demonstrate that the intervention was not only effective in the short term but also capable of producing durable changes that persisted beyond the active intervention phase.

The primary outcomes indicate that the intervention significantly reduced BMI, with a mean decrease of 0.8 kg/m² and approximately 75% of this improvement maintained at the 12-month follow-up. Substantial gains were also observed in motor skill development across multiple domains, reflected by a 19% composite improvement and large effect sizes, more than half of which were sustained at follow-up. In parallel, sleep health improved markedly, as evidenced by a 1.8-point reduction in PSQI-C scores and an increase of 1.8 hours in sleep duration, with most benefits persisting after 12 months. Objectively measured physical activity further confirmed behavioral change, showing significant increases in daily moderate-to-vigorous physical activity during the intervention and sustained elevation at follow-up.

The consistency of these findings provides strong support for all proposed hypotheses, including reductions in BMI, improvements in motor skills and sleep quality, and the sustainability of intervention effects over time. Although partial attenuation of outcomes was observed at follow-up, the maintenance of significant benefits across all primary measures suggests that the intervention produced genuine developmental and behavioral adaptations rather than transient effects. From a developmental perspective, improvements in motor competence during middle childhood likely reflect successful exploitation of a critical period of motor plasticity, with potential long-term implications for sustained physical activity participation.

Overall, this study underscores the broader significance of school-based physical activity interventions as feasible, inclusive, and effective strategies for comprehensive child health promotion. The simultaneous improvements in body composition, motor competence, sleep health, and physical activity behavior highlight the synergistic benefits of integrated movement-based approaches. These findings support the prioritization of structured physical activity within school curricula, emphasize the need for ongoing support to sustain long-term benefits, and provide a strong evidence base for policymakers, educators, and public health practitioners seeking scalable solutions to address childhood obesity, motor skill deficits, and sleep disturbances at the population level.

ACKNOWLEDGMENTS

The authors express gratitude to the participating schools, children, and families whose cooperation made this investigation possible. We acknowledge the dedicated efforts of research assistants who conducted data collection and intervention implementation.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest. No financial relationships, personal connections, or competing interests exist that could bias the interpretation of research findings or represent undisclosed conflicts with the sponsoring organization or funding sources.

REFERENCES

Acevedo, A. R., Story, D., Werner, L., Barker, D., McGeary, J. E., Dunsiger, S., & Grigsby-Toussaint, D. S. (2025). Associations between objectively and subjectively measured sleep outcomes among elementary school children in Rhode Island. *Frontiers in Pediatrics*, *13*. https://doi.org/10.3389/fped.2025.1622943

Arthur, W., Day, E. A., Villado, A. J., Boatman, P. R., Kowollik, V., Bennett, W., & Bhupatkar, A. (2007). *Decay, Transfer, and the Reacquisition of a Complex Skill: An Investigation of Practice Schedules, Observational Rehearsal, and Individual Differences*. https://apps.dtic.mil/sti/pdfs/ADA482766.pdf

Astill, R. G., Heijden, K. B. van der, IJzendoorn, M. H. van, & Someren, E. J. W. V. (2012). Sleep, cognition, and behavioral problems in school-age children: A century of research meta-analyzed. [Review of *Sleep, cognition, and behavioral problems in school-age children: A century of research meta-analyzed.*]. *Psychological Bulletin*, *138*(6), 1109. American Psychological Association. https://doi.org/10.1037/a0028204

Bardid, F., Utesch, T., Stodden, D. F., & Lenoir, M. (2021). Developmental perspectives on motor competence and physical fitness in youth. *Scandinavian Journal of Medicine and Science in Sports*, *31*, 5. https://doi.org/10.1111/sms.13946

Bloch, M., Cordovil, R., Rodrigues, L. P., Martins, C., Braga, M. M., Vale, S., Proença, R., Brito, J., Guilherme, J., Neto, C., Seabra, A., & Costa, J. A. (2025). The impact of a school-based physical activity program on children's movement behaviors, aerobic fitness and motor competence: a follow up study. *Frontiers in Sports and Active Living*, *7*, 1541862. https://doi.org/10.3389/fspor.2025.1541862

Buman, M. P., & King, -Abby C. (2010). Exercise as a Treatment to Enhance Sleep. *American Journal of Lifestyle Medicine*, *4*(6), 500. https://doi.org/10.1177/1559827610375532

Button, A. M., Webster, E. K., Kracht, C. L., Hendrick, C., Okely, A. D., Chong, K. H., Cross, P., & Staiano, A. E. (2023). Validation of remote assessment of preschool children's anthropometrics and motor skills. *Frontiers in Digital Health*, *5*. https://doi.org/10.3389/fdgth.2023.1168618

Chaput, J., Willumsen, J., Bull, F., Chou, R., Ekelund, U., Firth, J., Jago, R., Ortega, F. B., & Katzmarzyk, P. T. (2020). 2020 WHO guidelines on physical activity and sedentary behaviour for children and adolescents aged 5–17 years: summary of the evidence [Review of *2020 WHO guidelines on physical activity and sedentary behaviour for children and adolescents aged 5–17 years: summary of the evidence*]. *International Journal of Behavioral Nutrition and Physical Activity*, *17*(1), 141. BioMed Central. https://doi.org/10.1186/s12966-020-01037-z

Christiansen, L., Larsen, M. N., Madsen, M. A. J., Grey, M. J., Nielsen, J. B., & Lundbye-Jensen, J. (2020). Long-term motor skill training with individually adjusted progressive difficulty enhances learning and promotes corticospinal plasticity. *Scientific Reports*, *10*(1). https://doi.org/10.1038/s41598-020-72139-8

Combs, K. M., Drewelow, K. M., Lain, M. A., Habesland, M. S., Ippolito, A., & Finigan-Carr, N. (2022). Sustainment of an Evidence-Based, Behavioral Health Curriculum in Schools. *Prevention Science*, *24*(3), 541. https://doi.org/10.1007/s11121-022-01454-5

Cools, W., Martelaer, K. D., Samaey, C., & Andries, C. (2009). Movement skill assessment of typically developing preschool children: a review of seven movement skill assessment tools. [Review of *Movement skill assessment of typically developing preschool children: a review of seven movement skill assessment tools.*]. *PubMed*, *8*(2), 154. National Institutes of Health. https://pubmed.ncbi.nlm.nih.gov/24149522

Coppens, E., Rommers, N., Bardid, F., Deconinck, F., Martelaer, K. D., D'Hondt, E., & Lenoir, M. (2020). Long-term effectiveness of a fundamental motor skill intervention in Belgian children: A 6-year follow-up. *Scandinavian Journal of Medicine and Science in Sports*, *31*, 23. https://doi.org/10.1111/sms.13898

Demetriou, Y., Gillison, F., & McKenzie, T. L. (2017). After-School Physical Activity Interventions on Child and Adolescent Physical Activity and Health: A Review of Reviews [Review of *After-School Physical Activity Interventions on Child and Adolescent Physical Activity and Health: A Review of Reviews*]. *Advances in Physical Education*, *7*(2), 191. Scientific Research Publishing. https://doi.org/10.4236/ape.2017.72017

Dhuli, K., Naureen, Z., Medori, M. C., Fioretti, F., Caruso, P., Perrone, M. A., Nodari, S., Manganotti, P., Xhufi, S., Bushati, M., Bozo, D., Connelly, S. T., Herbst, K. L., & Bertelli, M. (2022). *Physical activity for health*. https://doi.org/10.15167/2421-4248/jpmh2022.63.2S3.2756

Dobbins, M., Husson, H., DeCorby, K., & LaRocca, R. L. (2013). School-based physical activity programs for promoting physical activity and fitness in children and adolescents aged 6 to 18 [Review of *School-based physical activity programs for promoting physical activity and fitness in children and adolescents aged 6 to 18*]. *Cochrane Library*. Elsevier BV. https://doi.org/10.1002/14651858.cd007651.pub2

Dumpa, V., & Bhandari, V. (2021). Non-Invasive Ventilatory Strategies to Decrease Bronchopulmonary Dysplasia—Where Are We in 2021? *Children*, *8*(2), 132. https://doi.org/10.3390/children8020132

Ekstedt, M., Nyberg, G., Ingre, M., Ekblom, Ö., & Marcus, C. (2013). Sleep, physical activity and BMI in six to ten-year-old children measured by accelerometry: a cross-sectional study. *International Journal of Behavioral Nutrition and Physical Activity*, *10*(1), 82. https://doi.org/10.1186/1479-5868-10-82

Grydeland, M., Bjelland, M., Anderssen, S. A., Klepp, K., Bergh, I. H., Andersen, L. F., Ommundsen, Y., & Lien, N. (2013). Effects of a 20-month cluster randomised controlled school-based intervention trial on BMI of school-aged boys and girls: the HEIA study. *British Journal of Sports Medicine*, *48*(9), 768. https://doi.org/10.1136/bjsports-2013-092284

Huang, G., Yao, J., Deng, L., Huang, P., Hong, P., & Li, X. (2025). Effects of a structured after-school physical activity program on physical fitness, body composition, and sleep in primary school students: a pilot quasi-experimental study. *BMC Public Health*, *26*(1), 123. https://doi.org/10.1186/s12889-025-25843-x

Ibri, L., & Çupi, B. (2025). Investigating Parental Attitudes and Perspectives on the Importance of Physical Activity in Early Childhood Education. *Journal Human Research in Rehabilitation*, *15*(2), 287. https://doi.org/10.21554/hrr.092504

Kao, H.-F., Lin, C.-F., Lin, I.-T., Hung, Y.-C., Chang, T., & Ho, C.-C. (2025). Improved Sleep Quality and Sleep Duration After an 8-Week Exergaming Intervention for Exercise Training Among Elementary Schoolchildren in Taiwan. *Children*, *12*(2), 180. https://doi.org/10.3390/children12020180

Kelly, A. S., Fox, C. K., Rudser, K. D., Gross, A. C., & Ryder, J. R. (2016). Pediatric obesity pharmacotherapy: current state of the field, review of the literature and clinical trial considerations. *International Journal of Obesity*, *40*(7), 1043. https://doi.org/10.1038/ijo.2016.69

Kerr, J. A., Patton, G., Cini, K., Abate, Y. H., Abbas, N., Magied, A. H. A. A. A., ElHafeez, S. A., Abd-Elsalam, S., Abdollahi, A., Abdoun, M., Abdulah, D. M., Abdulkader, R. S., Abdullahi, A., Abeywickrama, H. M., Abie, A., Abiodun, O., Abohashem, S., Abtahi, D., Abualruz, H., … Alvis-Guzmán, N. (2025). Global, regional, and national prevalence of child and adolescent overweight and obesity, 1990–2021, with forecasts to 2050: a forecasting study for the Global Burden of Disease Study 2021. *The Lancet*, *405*(10481), 785. https://doi.org/10.1016/s0140-6736(25)00397-6

Key Global Organizations. (2020). In *Palgrave Macmillan UK eBooks* (p. 3). Palgrave Macmillan. https://doi.org/10.1057/978-1-349-95940-2_1

Korkutata, A., Korkutata, M., & Lazarus, M. (2025). The impact of exercise on sleep and sleep disorders. *Deleted Journal*, *2*(1). https://doi.org/10.1038/s44323-024-00018-w

Kouros, C. D., & El-Sheikh, M. (2016). Within-Family Relations in Objective Sleep Duration, Quality, and Schedule. *Child Development*, *88*(6), 1983. https://doi.org/10.1111/cdev.12667

Levesque, R. J. R. (2017). *Obesity and Overweight* (p. 1). https://doi.org/10.1007/978-3-319-32132-5_447-2

Lorås, H. (2020). The Effects of Physical Education on Motor Competence in Children and Adolescents: A Systematic Review and Meta-Analysis [Review of *The Effects of Physical Education on Motor Competence in Children and Adolescents: A Systematic Review and Meta-Analysis*]. *Sports*, *8*(6), 88. Multidisciplinary Digital Publishing Institute. https://doi.org/10.3390/sports8060088

Mariano, M. A., Tang, K., Kurtz, M. M., & Kates, W. R. (2016). Examining the durability of a hybrid, remote and computer-based cognitive remediation intervention for adolescents with 22q11.2 deletion syndrome. *Early Intervention in Psychiatry*, *12*(4), 686. https://doi.org/10.1111/eip.12367

Maślak, A., Kusz, M., Pawluczuk, P., Alzubedi, A., & Polski, P. (2020). Causes of overweight and obesity in children and adolescents. *Journal of Education Health and Sport*, *10*(5), 11. https://doi.org/10.12775/jehs.2020.10.05.001

Meester, A. D., Stodden, D. F., Brian, A., True, L., Cardon, G., Tallir, I., & Haerens, L. (2016). Associations among Elementary School Children's Actual Motor Competence, Perceived Motor Competence, Physical Activity and BMI: A Cross-Sectional Study. *PLoS ONE*, *11*(10). https://doi.org/10.1371/journal.pone.0164600

Min, H. J., Park, S. H., Lee, S., Lee, B.-H., Kang, M.-K., Kwon, M. J., Chang, M. J., Negi, L. T., Samphel, T., & Won, S. (2024). Building Resilience and Social–Emotional Competencies in Elementary School Students through a Short-Term Intervention Program Based on the SEE Learning Curriculum. *Behavioral Sciences*, *14*(6), 458. https://doi.org/10.3390/bs14060458

Mitchell, J. J., Bu, F., Fancourt, D., Steptoe, A., & Bone, J. K. (2022). Longitudinal associations between physical activity and other health behaviours during the COVID-19 pandemic: A fixed effects analysis. *Research Square (Research Square)*. https://doi.org/10.21203/rs.3.rs-1807928/v1

Moon, J., Webster, C. A., Stodden, D. F., Brian, A., Mulvey, K. L., Beets, M. W., Egan, C. A., McIntosh, L. I. F., Merica, C. B., & Russ, L. (2024). Systematic review and meta-analysis of physical activity interventions to increase elementary children's motor competence: a comprehensive school physical activity program perspective [Review of *Systematic review and meta-analysis of physical activity interventions to increase elementary children's motor competence: a comprehensive school physical activity program perspective*]. *BMC Public Health*, *24*(1). BioMed Central. https://doi.org/10.1186/s12889-024-18145-1

Nilsen, A. K. O., Anderssen, S. A., Johannessen, K., Aadland, K. N., Ylvisaaker, E., Loftesnes, J. M., & Aadland, E. (2020). Bi-directional prospective associations between objectively measured physical activity and fundamental motor skills in children: a two-year follow-up. *International Journal of Behavioral Nutrition and Physical Activity*, *17*(1), 1. https://doi.org/10.1186/s12966-019-0902-6

Reilly, J. J., Kelly, L. A., Montgomery, C., Williamson, A., Fisher, A., McColl, J. H., Conte, R. L., Paton, J. Y., & Grant, S. (2006). Physical activity to prevent obesity in young children: cluster randomised controlled trial. *BMJ*, *333*(7577), 1041. https://doi.org/10.1136/bmj.38979.623773.55

Sanyaolu, A., Okorie, C., Qi, X., Locke, J. A., & Rehman, S. (2019). Childhood and Adolescent Obesity in the United States: A Public Health Concern. *Global Pediatric Health*, *6*. https://doi.org/10.1177/2333794x19891305

Singh, A. (2012). Physical Activity and Performance at School [Review of *Physical Activity and Performance at School*]. *Archives of Pediatrics and Adolescent Medicine*, *166*(1), 49. American Medical Association. https://doi.org/10.1001/archpediatrics.2011.716

Soorya, L., Siper, P. M., Beck, T., Soffes, S., Halpern, D., Gorenstein, M., Kolevzon, A. lexander, Buxbaum, J. D., & Wang, A. T. (2014). Randomized Comparative Trial of a Social Cognitive Skills Group for Children With Autism Spectrum Disorder. *Journal of the American Academy of Child & Adolescent Psychiatry*, *54*(3), 208. https://doi.org/10.1016/j.jaac.2014.12.005

Torres-Lopez, L. V., Migueles, J. H., Cadenas-Sánchez, C., Bendtsen, M., Henriksson, P., Mora-González, J., Löf, M., Chaput, J., & Ortega, F. B. (2022). Effects of exercise on sleep in children with overweight/obesity: A randomized clinical trial. *medRxiv (Cold Spring Harbor Laboratory)*. https://doi.org/10.1101/2022.09.23.22280266

Tremblay, M. S., Chaput, J., Adamo, K. B., Aubert, S., Barnes, J. D., Choquette, L., Duggan, M., Faulkner, G., Goldfield, G. S., Gray, C., Gruber, R., Janson, K., Janssen, I., Janssen, X., Garcia, A. J., Kuzik, N., LeBlanc, C., MacLean, J. E., Okely, A. D., … Carson, V. (2017). Canadian 24-Hour Movement Guidelines for the Early Years (0–4 years): An Integration of Physical Activity, Sedentary Behaviour, and Sleep. *BMC Public Health*, *17*. https://doi.org/10.1186/s12889-017-4859-6

Weiss, M. R. (2020). Motor Skill Development and Youth Physical Activity: A Social Psychological Perspective. *Journal of Motor Learning and Development*, *8*(2), 315. https://doi.org/10.1123/jmld.2020-0009

Zapalac, K., Miller, M., Champagne, F. A., Schnyer, D. M., & Baird, B. (2024). The effects of physical activity on sleep architecture and mood in naturalistic environments. *Scientific Reports*, *14*(1), 5637. https://doi.org/10.1038/s41598-024-56332-7