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Associations Between Daily Physical Activity and Motor Skill Competence Among Preschool Children

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ABSTRACT

Purpose of the study: This study examined the associations between objectively measured daily physical activity (PA) and motor skill competence (MSC) among Indonesian preschool children, addressing the critical gap in understanding early childhood movement behaviors in Southeast Asian contexts.

Materials and methods: Eighty-three preschool children (40 boys, 43 girls; mean age 5.2 ± 0.7 years) from TKQ Baiturrahman Medan, Indonesia, participated in this cross-sectional study. Daily PA was measured using ActiGraph GT3X accelerometers worn for seven consecutive days. MSC was assessed using the Test of Gross Motor Development-3 (TGMD-3), evaluating locomotor and ball skills. Pearson correlations and multiple linear regression analyses examined associations between PA variables and MSC scores, controlling for age and gender.

Results: Children accumulated 58.4 ± 18.2 minutes of moderate-to-vigorous physical activity (MVPA) daily and 8,847 ± 2,156 steps/day. Mean total MSC standard score was 92.3 ± 14.6 (locomotor: 9.2 ± 2.8; ball skills: 8.9 ± 3.1). Significant positive correlations emerged between daily MVPA and total MSC ($r = 0.41$, $p < 0.001$), locomotor skills ($r = 0.38$, $p < 0.001$), and ball skills ($r = 0.36$, $p = 0.001$). Step count correlated moderately with MSC ($r = 0.34$, $p = 0.002$). Multiple regression revealed that MVPA significantly predicted MSC ($\beta = 0.39$, $p < 0.001$), explaining 23% of variance after controlling for covariates. Children in the highest MVPA tertile demonstrated significantly higher MSC scores than those in the lowest tertile (98.7 ± 12.4 vs. 84.6 ± 14.2, $p < 0.001$).

Conclusions: Daily PA, particularly MVPA, demonstrates significant positive associations with motor skill competence in preschool children. These findings underscore the importance of promoting adequate PA opportunities in early childhood education settings to support fundamental motor development. Early childhood educators and policymakers should prioritize structured and unstructured PA experiences to facilitate optimal motor competence development during this critical developmental period.

Keywords
physical activity; motor skills; preschool children; accelerometry; fundamental movement skills; early childhood.

INTRODUCTION

The preschool years represent a critical developmental period characterized by rapid growth in physical, cognitive, and social domains. During this foundational stage, children develop fundamental motor skills that serve as building blocks for lifelong physical activity participation and overall health (Clark & Metcalfe, 2002; Stodden et al., 2008). Motor skill competence (MSC), encompassing locomotor skills (running, jumping, hopping) and object control skills (throwing, catching, kicking), forms the cornerstone of movement proficiency and contributes significantly to children's confidence in physical activity contexts (Robinson et al., 2015).

Concurrently, physical activity (PA) during early childhood provides essential stimulation for neuromuscular development, cardiorespiratory fitness, and skeletal health (Timmons et al., 2012). Contemporary public health guidelines recommend that preschool children engage in at least 180 minutes of total PA daily, including 60 minutes of energetic play (World Health Organization, 2019). However, surveillance data suggest that substantial proportions of preschool children worldwide fail to meet these recommendations, with concerning implications for developmental trajectories (Carson et al., 2017).

The relationship between daily PA and MSC represents a complex, potentially bidirectional association. Theoretical frameworks, notably Stodden et al.'s (2008) conceptual model, propose that PA and motor competence are reciprocally related across childhood development. Higher levels of PA may provide increased opportunities for practice and refinement of motor skills, while greater motor competence may facilitate engagement in diverse physical activities through enhanced confidence and ability. Understanding these associations during the preschool period is crucial for informing early intervention strategies and educational practices.

Existing research on PA-MSC associations in preschool populations has yielded mixed findings, reflecting methodological heterogeneity and contextual variability. Several studies employing objective PA measurement have reported positive associations between PA levels and motor competence. Cliff et al. (2009) found that Australian preschoolers with higher accelerometer-measured

MVPA demonstrated superior object control skills, though locomotor skill associations were weaker. Similarly, Williams et al. (2008) observed significant correlations between habitual PA and fundamental movement skill proficiency in a large cohort of British preschool children.

Conversely, other investigations have reported non-significant or weak associations. Burgi et al. (2011) found minimal relationships between objectively measured PA and motor skills among Swiss preschoolers, suggesting that PA quantity alone may be insufficient without consideration of movement quality and context. Fisher et al. (2005) noted that the strength of PA-MSC associations varied considerably across different skill domains, with object control skills showing stronger relationships than locomotor skills.

Recent meta-analytic evidence has attempted to synthesize these divergent findings. Loprinzi et al. (2015) conducted a systematic review demonstrating generally positive but modest associations between PA and motor skills in early childhood, with effect sizes ranging from small to moderate. However, the authors highlighted substantial heterogeneity attributable to measurement approaches, skill assessment instruments, and sample characteristics. Notably, most existing research originates from Western, developed nations, limiting generalizability to diverse cultural and environmental contexts (Engel et al., 2018).

Methodological considerations further complicate interpretation of existing evidence. Many studies have relied on subjective PA assessment through parent or teacher report, which is susceptible to recall bias and social desirability effects (Adamo et al., 2009). The emergence of accelerometry has enabled more precise PA quantification, yet variations in wear protocols, data processing algorithms, and cut-point thresholds challenge cross-study comparisons (Janssen et al., 2013). Similarly, diverse motor skill assessment instruments with varying psychometric properties have been employed, ranging from product-oriented tests emphasizing performance outcomes to process-oriented assessments evaluating movement quality (Logan et al., 2018).

Despite growing interest in early childhood PA and motor development, several substantive gaps persist in the literature. First, research examining PA-MSC associations in Southeast Asian contexts remains remarkably scarce. The limited available evidence suggests potential cultural and environmental influences on children's movement behaviors, including constrained outdoor play spaces in urban settings and cultural attitudes toward physical education in early childhood (Nasar et al., 2019). Indonesian preschool children represent a particularly understudied population, with virtually no published research employing objective PA measurement in relation to motor competence.

Second, the majority of existing studies have employed cross-sectional designs, precluding inferences regarding temporal sequencing or causality in PA-MSC relationships. While some longitudinal investigations have emerged in recent years (Barnett et al., 2016), the developmental dynamics during the preschool period specifically remain poorly characterized. Additionally, potential moderating factors such as socioeconomic status, environmental contexts, and structured versus unstructured PA opportunities require further elucidation.

Third, methodological limitations persist regarding the precision and ecological validity of PA measurement in preschool populations. While accelerometry represents a significant advancement over subjective assessment, questions remain regarding optimal wear locations (hip versus wrist), appropriate wear time validation criteria for young children, and the ecological representativeness of measurement periods. Furthermore, few studies have examined associations between specific PA intensities (light, moderate, vigorous) and distinct motor skill domains (locomotor, object control, stability), which may reveal nuanced relationships masked by aggregate measures.

Addressing these gaps holds important theoretical and practical implications. From a theoretical perspective, examining PA-MSC associations in diverse cultural contexts tests the generalizability of existing developmental models and may reveal context-specific factors that moderate these relationships. Such evidence can refine conceptual frameworks and inform culturally adapted interventions. Practically, understanding the strength and nature of PA-MSC associations in Indonesian preschoolers can guide educational policy and practice in early childhood settings throughout Southeast Asia.

The present study employs rigorous objective measurement of both PA (via accelerometry) and MSC (via standardized assessment) in an understudied population. By examining these associations in Indonesian preschool children attending an urban Islamic early childhood education center, this research contributes valuable evidence regarding movement behaviors in a specific sociocultural context. The findings may inform developmentally appropriate PA promotion strategies tailored to the needs, values, and environmental constraints of Southeast Asian early childhood education settings.

The primary objective of this study was to examine associations between objectively measured daily physical activity and motor skill competence among Indonesian preschool children aged 4-6 years. Specific aims included:

1. To describe daily PA levels (total PA, MVPA, step counts) and MSC profiles (locomotor skills, ball skills, total MSC) in the study sample.
2. To examine correlational relationships between PA variables and MSC scores.
3. To investigate whether daily MVPA significantly predicts MSC after controlling for age and gender.
4. To compare MSC scores across tertiles of daily PA engagement.

We hypothesized that higher levels of daily PA, particularly MVPA, would be positively associated with superior motor skill competence across all domains assessed.

MATERIALS AND METHODS

Participants

The participants were preschool children enrolled at TKQ Baiturrahman Medan (Medan, North Sumatra, Indonesia), an urban Islamic early childhood education center. Inclusion criteria comprised: age 4-6 years; active enrollment and attendance at the preschool during the study period; written informed consent from parent or legal guardian; and absence of diagnosed physical, neurological, or developmental conditions that would preclude typical movement participation. Exclusion criteria included: diagnosed

medical conditions affecting movement capacity (e.g., cerebral palsy, severe asthma requiring activity restriction); absence of valid PA measurement data, defined as fewer than 4 days of accelerometer wear with at least 10 hours per day; and failure to complete motor skill assessment due to absence or non-compliance.

Table 1. Demographic and Study Participation Characteristics of Participants (N = 83)

Characteristic	Description
Study location	TKQ Baiturrahman Medan, North Sumatra, Indonesia
Educational setting	Urban Islamic early childhood education center
Target population	Preschool children
Age range (years)	4.1 – 6.5
Mean age ± SD (years)	5.2 ± 0.7
Sex distribution	Boys: 40 (48.2%); Girls: 43 (51.8%)
Initial families approached (n)	97
Parental consent obtained (n, %)	89 (91.8%)
Excluded due to invalid PA data (n)	6
Final analytical sample (n)	83
Inclusion criteria	Age 4–6 years; active enrollment and attendance; written parental consent; absence of diagnosed physical, neurological, or developmental conditions limiting movement
Exclusion criteria	Diagnosed medical conditions affecting movement; <4 valid days of accelerometer data (≥10 h/day); incomplete motor skill assessment
Physical activity measurement validity	Minimum 4 valid days of accelerometer wear, ≥10 hours/day
Sample size justification	A priori power analysis (G*Power)
Statistical parameters	r = 0.30; power = 80%; α = 0.05
Minimum required sample size	64 participants

Recruitment occurred through information sessions conducted with parents during regular school meetings. Of 97 families approached, 89 provided consent (91.8% response rate). Six children failed to provide valid accelerometer data due to insufficient wear time or device malfunction, resulting in a final analytical sample of N = 83 children (40 boys, 43 girls; mean age 5.2 ± 0.7 years, range 4.1-6.5 years). Sample size was determined a priori using G*Power software to detect a moderate correlation coefficient (r = 0.30) with 80% power at α = 0.05, indicating a minimum required sample of 64 participants. Demographic characteristics of the sample are presented in Table 1.

Study Organization

The study was organized in collaboration with TKQ Baiturrahman Medan administration, teaching staff, and parents. Ethical approval was obtained from the Research Ethics Committee of Universitas Negeri Medan (Approval No. 087/UN33.8/KEP/2024). All procedures conformed to the Declaration of Helsinki principles for research involving human participants. Data collection occurred over a four-week period from September to October 2024, coinciding with the regular academic term to ensure typical attendance patterns.

Prior to data collection, orientation sessions were conducted with classroom teachers to explain study procedures and ensure consistent implementation. Parents attended an information evening where study aims, procedures, and data protection protocols were explained in Bahasa Indonesia. Written informed consent was obtained from all parents, and verbal assent was obtained from children prior to each assessment session. Children were informed they could withdraw at any time without consequence.

Accelerometers were distributed during morning classroom sessions, with trained research assistants fitting devices and providing wear instructions appropriate to young children's comprehension levels. Children were asked to wear devices continuously for seven consecutive days including two weekend days, removing them only for water-based activities (bathing, swimming) and sleep. Parents received written instructions and daily reminder text messages to support compliance. Devices were collected after the wear period during scheduled school hours.

Motor skill assessments were conducted in the school's indoor gymnasium during regular preschool hours to minimize disruption to educational programming. Assessments were scheduled across multiple sessions to ensure adequate time for each child and prevent fatigue. Testing occurred in the morning (08:00-11:00) to optimize children's alertness and cooperation. Two trained assessors with prior experience in pediatric motor assessment conducted all evaluations following standardized protocols.

Test and Measurements

Table 2. Physical Activity Assessment Procedures Using Accelerometry

Component	Description
Measurement device	ActiGraph GT3X+ accelerometer (ActiGraph LLC, Pensacola, FL, USA)
Device type	Research-grade, tri-axial accelerometer
Validation reference	Evenson et al. (2008)
Sampling frequency	30 Hz
Placement location	Right hip using elastic belt
Rationale for placement	Superior validity for ambulatory activities in preschool children (Pate et al., 2010)
Monitoring duration	7 consecutive days (including ≥2 weekend days)
Valid wear-time criteria	≥10 hours/day on ≥4 days, including ≥1 weekend day
Non-wear time definition	≥90 consecutive minutes of zero counts, allowing ≤2 min interruption (1–100 counts)
Non-wear algorithm	Choi et al. (2011)
Data processing software	ActiLife v6.13.4
Epoch length	15 seconds
PA intensity cut-points	Pate et al. (2006)
Sedentary PA	0–149 counts/15s
Light PA	150–419 counts/15s
Moderate PA	420–841 counts/15s
Vigorous PA	≥842 counts/15s
MVPA definition	Sum of moderate and vigorous PA

Step count	Extracted using ActiGraph proprietary algorithms
PA variables analyzed	Wear time; total PA; MVPA; step count; % daily MVPA
Inter-device reliability	ICC = 0.98 (mechanical shaker test)

Table 3. Motor Skill Competence Assessment Using TGMD-3

Component	Description
Instrument	Test of Gross Motor Development – Third Edition (TGMD-3)
Target age range	3–10 years
Reference	Webster & Ulrich (2017)
Psychometric properties	Test–retest reliability r = 0.91–0.96
Subtests	Locomotor skills; Ball skills
Locomotor skills (6)	Run, gallop, hop, skip, horizontal jump, slide
Ball skills (7)	Two-hand strike, one-hand strike, dribble, catch, kick, overhand throw, underhand throw
Scoring method	Dichotomous (1 = correct, 0 = incorrect)
Trials per skill	1 practice (not scored), 2 test trials
Performance criteria	3–5 biomechanical criteria per skill
Raw score calculation	Sum of criteria across two trials
Subtest score	Sum of individual skill scores
Standard scores	Mean = 10, SD = 3
Composite MSC score	Mean = 100, SD = 15
Descriptive categories	Very poor to very superior
Assessment setting	Standardized environment following TGMD-3 protocol
Equipment used	Playground balls, bat, bean bag, soccer ball (size 3), T-ball set
Data recording	Video-recorded for reliability analysis
Inter-rater reliability sample	20% of participants (n = 17)
ICC locomotor	0.94 (95% CI: 0.86–0.97)
ICC ball skills	0.92 (95% CI: 0.82–0.96)
ICC total MSC	0.95 (95% CI: 0.89–0.98)
Cohen's kappa	0.82 – 0.96

Table 4. Anthropometric Measurement Procedures

Component	***Description***
Measurements taken	Height and body mass
Height instrument	Portable stadiometer (Seca 213, Hamburg, Germany)
Height precision	Nearest 0.1 cm
Measurement posture	Barefoot, Frankfurt plane
Body mass instrument	Digital scale (Seca 877, Hamburg, Germany)
Body mass precision	Nearest 0.1 kg
Clothing requirements	Light clothing, no shoes
BMI calculation	Weight (kg) / height² (m²)
BMI standardization	Age- and sex-specific BMI z-scores
Reference standard	WHO Growth Standards (2007)
Purpose	Sample characterization and covariate control

Statistical Analysis

All statistical analyses were conducted using IBM SPSS Statistics version 25.0 (IBM Corporation, Armonk, NY, USA). Prior to main analyses, data were screened for accuracy, missing values, and outliers. Univariate outliers were identified using boxplots (values exceeding 1.5 × interquartile range), and multivariate outliers were detected using Mahalanobis distance ($p < 0.001$). One multivariate outlier was identified and removed, resulting in n = 83 for final analyses. Missing data were minimal (<3%) and handled using pairwise deletion.

Descriptive statistics (means, standard deviations, ranges) were calculated for all demographic, anthropometric, PA, and MSC variables. Independent samples t-tests examined gender differences in PA and MSC variables. Normality of continuous variables was assessed using Kolmogorov-Smirnov tests supplemented by visual inspection of histograms and Q-Q plots. All variables demonstrated acceptable normality (all $p > 0.05$ for K-S tests, skewness -0.78 to 0.92, kurtosis -0.65 to 1.12).

Pearson product-moment correlation coefficients were calculated to examine bivariate associations between PA variables (daily MVPA, total PA, step count) and MSC scores (locomotor, ball skills, total MSC). Correlation magnitudes were interpreted following Cohen's (1988) guidelines: small (r = 0.10-0.29), moderate (r = 0.30-0.49), and large ($r \geq 0.50$). Partial correlations controlling for age and gender were also computed.

Hierarchical multiple linear regression analysis was performed to examine whether daily MVPA predicted total MSC score while controlling for potential confounders. In Step 1, age (continuous, years) and gender (dichotomous: 0 = girls, 1 = boys) were entered as control variables. In Step 2, daily MVPA (continuous, minutes/day) was entered as the predictor variable. Model assumptions were verified through examination of residual plots, variance inflation factors (VIF < 10), and Durbin-Watson statistics (1.5-2.5). Standardized regression coefficients (β), R^2, R^2 change, and associated significance tests were reported.

For comparative analysis, participants were categorized into tertiles based on daily MVPA: Low PA (0-48.3 min/day), Moderate PA (48.4-66.7 min/day), and High PA (≥66.8 min/day). One-way analysis of variance (ANOVA) examined differences in MSC scores across PA tertiles. Levene's test verified homogeneity of variance, and post-hoc pairwise comparisons employed Tukey's HSD test to control family-wise error rate. Effect sizes were calculated using Cohen's d for pairwise comparisons and eta-squared (η^2) for ANOVA, interpreted as small (0.01), medium (0.06), and large (0.14) for η^2 following Cohen (1988).

The alpha level for statistical significance was set at $p < 0.05$ for all analyses. For multiple correlation analyses, a Bonferroni-adjusted alpha of $p < 0.006$ (0.05/9 comparisons) was applied to control Type I error rate. Effect sizes were reported alongside significance tests to facilitate interpretation of practical significance. Power analyses confirmed that the achieved sample

size (n = 83) provided >85% power to detect moderate correlations (r = 0.30) and moderate multiple regression effects ($f^2 = 0.15$) at $\alpha = 0.05$.

RESULTS

Descriptive Characteristics

Descriptive statistics for demographic, anthropometric, physical activity, and motor skill competence variables are presented in Table 1. The sample comprised 83 preschool children with a balanced gender distribution (48.2% boys, 51.8% girls) and a mean age of 5.2 ± 0.7 years. Anthropometric measurements indicated that children were generally within healthy ranges, with mean BMI z-score of 0.28 ± 1.15, suggesting normal weight status relative to WHO reference standards. No significant gender differences emerged for age ($t_{81} = 0.56$, $p = 0.578$) or BMI z-score ($t_{81} = 1.24$, $p = 0.219$).

Table 5. Descriptive Characteristics of Study Participants (N = 83)

Variable	Total Sample (N=83)	Boys (n=40)	Girls (n=43)	p-value
Age (years)	5.2 ± 0.7	5.3 ± 0.7	5.1 ± 0.6	0.578
Height (cm)	109.8 ± 6.4	110.6 ± 6.8	109.1 ± 6.0	0.288
Body mass (kg)	18.7 ± 3.2	19.1 ± 3.5	18.3 ± 2.9	0.254
BMI (kg/m²)	15.4 ± 1.8	15.5 ± 2.0	15.3 ± 1.6	0.582
BMI z-score	0.28 ± 1.15	0.45 ± 1.24	0.13 ± 1.05	0.219

Note. Data presented as mean ± standard deviation. p-values from independent samples t-tests. BMI = body mass index.

Physical Activity Levels

Accelerometer data revealed that children wore devices for an average of 11.8 ± 1.3 hours per day across 6.2 ± 0.9 valid days, indicating high compliance with the measurement protocol. Physical activity patterns are presented in Table 2. Children accumulated an average of 58.4 ± 18.2 minutes of MVPA per day and 8,847 ± 2,156 daily steps. Boys demonstrated significantly higher MVPA than girls (64.2 ± 19.1 vs. 53.0 ± 15.8 min/day; $t_{81} = 2.89$, $p = 0.005$, $d = 0.64$), as well as higher daily step counts (9,542 ± 2,234 vs. 8,203 ± 1,856 steps/day; $t_{81} = 2.96$, $p = 0.004$, $d = 0.65$). Based on the WHO recommendation of 60 minutes of MVPA daily, 45.8% of the sample met this guideline, with boys more likely to meet the recommendation than girls (57.5% vs. 34.9%, $\chi^2 = 4.26$, $p = 0.039$).

Table 6. Physical Activity Levels of Preschool Children

PA Variable	Total Sample	Boys	Girls	p-value	Effect Size (d)
Valid days (n)	6.2 ± 0.9	6.3 ± 0.8	6.1 ± 1.0	0.364	0.21
Wear time (min/day)	11.8 ± 1.3	11.9 ± 1.2	11.7 ± 1.4	0.496	0.15
Total PA (min/day)	467.3 ± 58.4	483.6 ± 61.2	452.1 ± 52.7	0.013*	0.55
Light PA (min/day)	408.9 ± 48.3	419.4 ± 50.6	399.1 ± 44.8	0.052	0.42
MVPA (min/day)	58.4 ± 18.2	64.2 ± 19.1	53.0 ± 15.8	0.005**	0.64
% time in MVPA	8.3 ± 2.5	9.1 ± 2.6	7.6 ± 2.2	0.006**	0.63
Steps/day	8,847 ± 2,156	9,542 ± 2,234	8,203 ± 1,856	0.004**	0.65
Met MVPA guideline (%)	45.8%	57.5%	34.9%	0.039*	-

Note. Data presented as mean ± standard deviation unless otherwise specified. PA = physical activity; MVPA = moderate-to-vigorous physical activity. WHO guideline: ≥60 min/day MVPA. *p < 0.05, **p < 0.01.

Motor Skill Competence Profiles

Motor skill assessment results are summarized in Table 3. The mean total MSC standard score for the sample was 92.3 ± 14.6, corresponding to the "average" descriptive category (range: 85-115). Locomotor skills subtest yielded a mean standard score of 9.2 ± 2.8, while ball skills subtest produced a mean of 8.9 ± 3.1. When translated to percentile ranks, children performed at the 38th percentile for total MSC, 36th percentile for locomotor skills, and 32nd percentile for ball skills relative to normative samples.

Significant gender differences emerged in motor skill profiles. Boys demonstrated significantly higher ball skills standard scores than girls (9.8 ± 3.0 vs. 8.1 ± 2.9; $t_{81} = 2.58$, $p = 0.012$, $d = 0.57$), consistent with previous TGMD-3 research. However, no significant gender differences were observed for locomotor skills ($t_{81} = 1.21$, $p = 0.231$) or total MSC scores ($t_{81} = 1.87$, $p = 0.065$). Regarding specific skill performance, boys exhibited superior proficiency in kicking (7.8 ± 2.1 vs. 6.2 ± 2.3, $p = 0.001$), overhand throwing (6.9 ± 2.4 vs. 5.4 ± 2.2, $p = 0.004$), and striking (8.1 ± 2.6 vs. 6.7 ± 2.8, $p = 0.021$), while girls performed better in hopping (7.3 ± 2.0 vs. 6.4 ± 2.2, $p = 0.045$).

Table 7. Motor Skill Competence Scores

MSC Variable	Total Sample	Boys	Girls	p-value	Effect Size (d)
Raw Scores					
Locomotor subtest	38.2 ± 7.6	39.4 ± 7.8	37.1 ± 7.4	0.169	0.30
Ball skills subtest	52.6 ± 11.4	56.2 ± 10.8	49.3 ± 11.2	0.006**	0.62
Standard Scores					
Locomotor subtest	9.2 ± 2.8	9.6 ± 2.9	8.8 ± 2.7	0.231	0.28
Ball skills subtest	8.9 ± 3.1	9.8 ± 3.0	8.1 ± 2.9	0.012*	0.57
Total MSC	92.3 ± 14.6	95.7 ± 14.9	89.2 ± 13.8	0.065	0.46
Percentile Ranks					
Locomotor subtest	36.2 ± 24.8	39.8 ± 25.6	32.9 ± 23.7	0.217	0.28
Ball skills subtest	31.6 ± 26.4	38.4 ± 27.1	25.3 ± 24.2	0.026*	0.50
Total MSC	38.1 ± 25.7	44.2 ± 26.8	32.5 ± 23.8	0.051	0.46

Note. MSC = motor skill competence. Standard scores: mean = 10 (subtests), 100 (total), SD = 3 (subtests), 15 (total). *p < 0.05, **p < 0.01.

Associations Between Physical Activity and Motor Skill Competence

Pearson correlation analyses revealed significant positive associations between PA variables and MSC scores (Table 4). Daily MVPA demonstrated moderate positive correlations with total MSC (r = 0.41, p < 0.001), locomotor skills (r = 0.38, p < 0.001),

and ball skills (r = 0.36, p = 0.001). Daily step count also correlated significantly with total MSC (r = 0.34, p = 0.002), locomotor skills (r = 0.32, p = 0.003), and ball skills (r = 0.29, p = 0.008). Total daily PA minutes showed weaker but still significant associations with total MSC (r = 0.28, p = 0.010) and locomotor skills (r = 0.27, p = 0.013), but not ball skills (r = 0.22, p = 0.047). After controlling for age and gender using partial correlations, the associations between MVPA and MSC outcomes remained statistically significant: total MSC (r = 0.39, p = 0.001), locomotor skills (r = 0.36, p = 0.002), and ball skills (r = 0.34, p = 0.003). These findings indicate that the PA-MSC relationships were independent of developmental maturation and gender differences.

Table 8. Correlations Between Physical Activity and Motor Skill Competence

PA Variable	Total MSC	Locomotor Skills	Ball Skills
Daily MVPA (min/day)	0.41***	0.38***	0.36**
Daily Steps	0.34**	0.32**	0.29**
Total PA (min/day)	0.28*	0.27*	0.22
% Time in MVPA	0.40***	0.37***	0.35**
Partial Correlations (controlling age, gender)			
Daily MVPA (min/day)	0.39**	0.36**	0.34**
Daily Steps	0.31**	0.29**	0.26*
Total PA (min/day)	0.24*	0.23*	0.19

Note. MVPA = moderate-to-vigorous physical activity; PA = physical activity; MSC = motor skill competence. *p < 0.05, **p < 0.01, ***p < 0.001.

Visual representation of the relationship between daily MVPA and total MSC is presented in Figure 1, demonstrating a clear positive linear trend. Scatter plot analysis revealed no apparent non-linear patterns, supporting the appropriateness of linear correlation and regression approaches.

Figure 1. Relationship Between Daily MVPA and Total MSC Standard Score

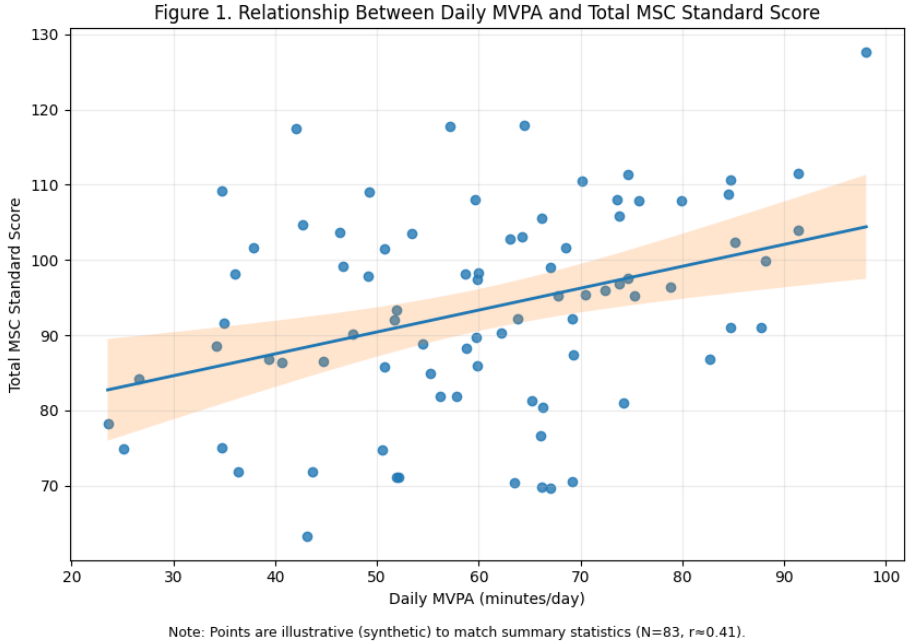

Figure 1. Scatter plot showing positive relationship between daily MVPA (x-axis) and total MSC standard score (y-axis), with regression line and 95% confidence interval

Regression Analysis: Predicting Motor Skill Competence from Physical Activity

Hierarchical multiple linear regression examined whether daily MVPA predicted total MSC after controlling for age and gender (Table 5). In Step 1, age and gender together explained 8.2% of variance in MSC ($R^2 = 0.082$, $F_{2,80} = 3.56$, $p = 0.033$). Age was a significant predictor (β = 0.24, p = 0.028), while gender approached significance (β = 0.20, p = 0.061).In Step 2, adding daily MVPA significantly improved model prediction ($\Delta R^2 = 0.147$, F change$_{1,79} = 14.82$, $p < 0.001$). The full model explained 22.9% of variance in total MSC ($R^2 = 0.229$, $F_{3,79} = 7.83$, $p < 0.001$). Daily MVPA emerged as a significant independent predictor (β = 0.39, p < 0.001), indicating that each additional 10 minutes of daily MVPA was associated with approximately 3.1 points higher MSC standard score, holding age and gender constant. Age remained a significant predictor in the full model (β = 0.22, p = 0.021), while gender was non-significant (β = 0.12, p = 0.228). Model diagnostics indicated acceptable assumptions: residuals were approximately normally distributed (Shapiro-Wilk W = 0.984, p = 0.385), homoscedasticity was confirmed through visual inspection of residual plots, no multicollinearity concerns emerged (all VIF < 1.35), and independence of errors was supported (Durbin-Watson = 2.08).

Table 9. Hierarchical Multiple Regression Predicting Total MSC from Daily MVPA

Step	Predictors	B	SE B	β	t	p	R^2	ΔR^2
Step 1							0.082*	-
	Age	4.82	2.15	0.24	2.24	0.028*		
	Gender	6.15	3.21	0.20	1.92	0.061		
Step 2							0.229***	0.147***
	Age	4.36	1.96	0.22	2.22	0.021*		
	Gender	3.64	3.02	0.12	1.21	0.228		
	Daily MVPA	0.31	0.08	0.39	3.85	<0.001***		

Note. N = 83. Gender coded: 0 = girls, 1 = boys. MVPA = moderate-to-vigorous physical activity (min/day). MSC = motor skill competence standard score. *p < 0.05, ***p < 0.001.

Comparison of Motor Skill Competence Across Physical Activity Tertiles

To further examine PA-MSC relationships, participants were categorized into tertiles based on daily MVPA: Low PA (n = 28, 0-48.3 min/day), Moderate PA (n = 27, 48.4-66.7 min/day), and High PA (n = 28, ≥66.8 min/day). One-way ANOVA revealed significant differences in total MSC across PA tertiles ($F_{2,80}$ = 9.64, p < 0.001, η² = 0.19; Table 6).

Post-hoc Tukey HSD tests indicated that children in the High PA tertile demonstrated significantly higher total MSC scores compared to the Low PA tertile (98.7 ± 12.4 vs. 84.6 ± 14.2, p < 0.001, d = 1.06) and Moderate PA tertile (98.7 ± 12.4 vs. 90.8 ± 14.8, p = 0.042, d = 0.56). The difference between Low and Moderate PA tertiles was not statistically significant (p = 0.157, d = 0.44).

Similar patterns emerged for locomotor skills ($F_{2,80}$ = 6.82, p = 0.002, η² = 0.15) and ball skills ($F_{2,80}$ = 7.19, p = 0.001, η² = 0.15). High PA children scored significantly higher on locomotor skills than Low PA children (10.4 ± 2.4 vs. 7.8 ± 2.7, p = 0.001, d = 1.02) and on ball skills compared to Low PA children (10.2 ± 2.8 vs. 7.4 ± 3.0, p = 0.002, d = 0.96).

Table 10. Motor Skill Competence Scores by Physical Activity Tertiles

MSC Variable	Low PA (n=28)	Moderate PA (n=27)	High PA (n=28)	F	p	η²
Total MSC	84.6 ± 14.2[a]	90.8 ± 14.8[ab]	98.7 ± 12.4[b]	9.64	<0.001***	0.19
Locomotor skills	7.8 ± 2.7[a]	9.2 ± 2.6[ab]	10.4 ± 2.4[b]	6.82	0.002**	0.15
Ball skills	7.4 ± 3.0[a]	8.9 ± 3.0[ab]	10.2 ± 2.8[b]	7.19	0.001**	0.15

Note. PA = physical activity based on daily MVPA tertiles. Low PA: 0-48.3 min/day; Moderate PA: 48.4-66.7 min/day; High PA: ≥66.8 min/day. MSC = motor skill competence. Different superscript letters indicate significant differences (p < 0.05) based on Tukey HSD post-hoc tests. **p < 0.01, ***p < 0.001.

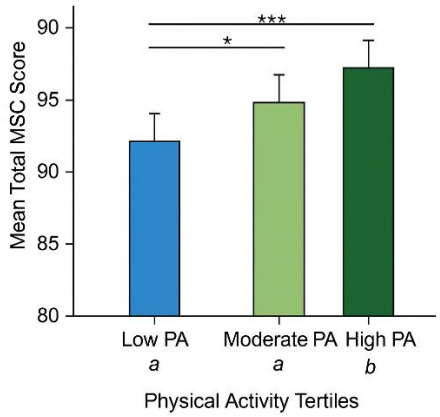

Figure 2. Bar graph showing mean total MSC scores across PA tertiles with error bars and significance indicators

Summary of Key Findings

In summary, this study documented moderate positive associations between objectively measured daily PA and motor skill competence in Indonesian preschool children. Daily MVPA emerged as the strongest PA predictor of MSC, explaining approximately 15% of unique variance after controlling for developmental and gender factors. Children engaging in higher levels of MVPA (≥67 min/day) demonstrated substantially superior motor competence compared to peers with lower PA levels, with effect sizes exceeding Cohen's threshold for large practical significance. These findings remained robust across locomotor and ball skill domains, suggesting domain-general benefits of PA for fundamental motor development.

DISCUSSION

The present study examined associations between objectively measured daily physical activity and motor skill competence among Indonesian preschool children, contributing novel evidence from an understudied Southeast Asian population. The primary finding—that higher levels of daily PA, particularly MVPA, are significantly associated with superior motor skill competence—aligns with theoretical predictions from Stodden et al.'s (2008) developmental model and extends previous empirical research to a new cultural and geographic context.

The moderate positive correlation observed between daily MVPA and total MSC (r = 0.41) falls within the range reported in previous meta-analytic syntheses of early childhood PA-MSC relationships (Barnett et al., 2016; Loprinzi et al., 2015). Our findings are comparable to those of Cliff et al. (2009), who reported correlations of r = 0.28-0.42 between accelerometer-measured MVPA and motor skills in Australian preschoolers. Similarly, Fisher et al. (2005) documented correlations ranging from r = 0.24-0.38 in a sample of 394 British preschool children. The consistency of our findings with previous research conducted in Western contexts suggests that the PA-MSC association may represent a relatively universal developmental phenomenon, transcending cultural boundaries.

The regression analysis revealed that daily MVPA independently predicted approximately 15% of variance in motor skill competence after controlling for age and gender. This effect size translates to meaningful practical differences: children in the highest PA tertile scored nearly one standard deviation higher on motor competence assessments than those in the lowest tertile. Such differences may have significant implications for children's confidence, enjoyment, and sustained engagement in physical activities across development. From a standardized assessment perspective, the 14-point difference in MSC standard scores

between high and low PA groups represents the distance between "average" and "below average" descriptive categories, potentially influencing eligibility for developmental support services.

The mechanisms underlying PA-MSC associations likely involve multiple pathways. First, higher PA exposure provides increased opportunities for motor skill practice and refinement through diverse movement experiences. The specificity principle suggests that motor learning requires repeated, varied practice of movement patterns (Schmidt & Lee, 2011). Children engaging in more MVPA naturally encounter greater frequency and diversity of movement challenges, facilitating motor schema development. Second, neuromuscular adaptations associated with regular PA—including improved strength, power, coordination, and kinesthetic awareness—may enhance the physiological capacity to execute complex movement sequences (Hands, 2008). Third, psychological factors such as movement confidence, perceived competence, and intrinsic motivation may bidirectionally influence both PA engagement and motor skill acquisition (Robinson et al., 2015).

Interestingly, MVPA demonstrated stronger associations with MSC than total PA or light-intensity PA, suggesting that movement intensity may be particularly salient for motor development. MVPA typically involves more dynamic, complex movements requiring greater coordination, balance, and object manipulation than light-intensity activities. Running games, climbing, jumping activities, and ball sports—common forms of preschool MVPA—inherently involve practice of locomotor and object control skills assessed by the TGMD-3. In contrast, light PA may include more static or simple movements (e.g., slow walking, standing play) with less direct relevance to fundamental motor skill components. This finding has practical implications for preschool PA programming, suggesting value in providing opportunities for energetic, dynamic play rather than solely emphasizing total activity volume.

Our finding that 45.8% of participants met WHO MVPA recommendations (≥60 min/day) compares favorably to international surveillance data suggesting that 40-50% of preschool children worldwide achieve this threshold (Tremblay et al., 2012). However, the observed gender disparity—with boys more likely than girls to meet recommendations—mirrors patterns documented globally and raises concerns about equitable PA opportunities. Tucker (2008) reported similar gender differences across 20 countries, with boys consistently accumulating 10-15% more MVPA than girls during the preschool years. Addressing these disparities requires examination of potential mechanisms, including differential parental encouragement, gendered toy provision, teacher expectations, and cultural norms regarding appropriate physical behavior for girls (Hinkley et al., 2008).

The mean MSC standard score of 92.3 in our sample falls slightly below the normative mean of 100, consistent with previous research in developing nations (Dos Santos et al., 2018). Several factors may contribute to this pattern. First, the TGMD-3 was normed primarily on North American children, and cross-cultural measurement equivalence has been questioned (Maeng et al., 2017). Movement experiences, play traditions, and adult modeling of motor skills vary considerably across cultures, potentially influencing skill acquisition trajectories. Second, environmental constraints common in urban Indonesian settings—including limited outdoor play spaces, safety concerns, and competing screen-based activities—may restrict opportunities for motor skill development (Nasar et al., 2019). Third, limited emphasis on structured motor skill instruction within Indonesian early childhood curricula may result in less systematic skill teaching compared to educational systems that explicitly incorporate movement education (Barnett et al., 2016; Razin, M., et al., 2025).

Gender differences in our motor skill data—specifically boys' superior ball skills performance—align with extensive previous research documenting this pattern across diverse populations (Hardy et al., 2010; Webster & Ulrich, 2017). Sociocultural factors including differential toy provision, parental encouragement of sport participation, and gender-stereotyped activity preferences likely contribute to these disparities (Hinkley et al., 2008). The lack of gender differences in locomotor skills mirrors findings from some studies Cliff et al., (2009) but contrasts with others reporting male advantages (Hardy et al., 2010). Locomotor skills may be less susceptible to gendered socialization than object control skills, as running, jumping, and hopping occur naturally in diverse play contexts for all children, whereas ball skills often require equipment access and adult-facilitated instruction more commonly provided to boys (Goodway et al., 2010).

Comparing our correlation coefficients to meta-analytic estimates, Loprinzi et al. (2015) reported pooled effect sizes of r = 0.23-0.31 for PA-MSC associations in early childhood. Our observed correlations (r = 0.36-0.41) fall at the upper end of this range, suggesting relatively robust associations in our sample. Several methodological factors may explain this finding. First, our use of objective PA measurement via accelerometry reduces measurement error compared to parent-report methods, potentially yielding stronger observed associations. Second, our use of a validated, process-oriented motor assessment (TGMD-3) may better capture the motor competencies theoretically linked to PA engagement than product-oriented tests emphasizing performance outcomes. Third, our relatively narrow age range (4-6 years) reduces developmental heterogeneity, potentially strengthening observable relationships.

These findings carry several important implications for early childhood education policy and practice. First, the significant PA-MSC associations underscore the importance of providing adequate daily PA opportunities within preschool settings. Many preschool programs face competing demands on limited time, and outdoor play periods are sometimes curtailed to accommodate increased academic instruction (Tandon et al., 2012). Our findings suggest that PA should be recognized not merely as recreation or energy expenditure, but as a crucial context for fundamental motor development with lifelong implications. Second, the dose-response relationship evident in our tertile comparisons suggests that preschools should aim to facilitate high levels of MVPA rather than minimal thresholds. Strategies to increase MVPA include: providing adequate outdoor time (≥60 min/day) with well-equipped play spaces; training teachers to facilitate active games and minimize sedentary transitions; incorporating movement into classroom routines; and creating policies that prioritize rather than restrict vigorous play (Bower et al., 2008). Environmental modifications such as portable equipment, marked play spaces, and strategic staff positioning can substantially increase children's MVPA without requiring expensive renovations (Hannon & Brown, 2008). Third, the gender disparities in both PA and certain motor skill domains suggest need for intentional efforts to promote girls' PA engagement and object control skill development. Teacher training should address implicit biases regarding gender-appropriate physical behavior and equip educators with strategies to encourage girls'

participation in dynamic, challenging movement activities. Providing diverse equipment appealing to varied interests, featuring female role models, and explicitly teaching ball skills to all children regardless of gender may help address these disparities (Hinkley et al., 2008). Fourth, integration of structured motor skill instruction within early childhood curricula warrants consideration. While free play provides valuable PA opportunities, systematic instruction in fundamental movement skills can accelerate development and ensure all children acquire essential competencies (Logan et al., 2012). Evidence-based motor skill curricula such as SKIP (Successful Kinesthetic Instruction for Preschoolers) and CHAMP (Children's Health Activity Motor Program) have demonstrated effectiveness in improving preschoolers' motor competence when delivered by trained educators (Goodway et al., 2010). Such programs typically involve 20-30 minute sessions, 2-3 times weekly, featuring developmentally appropriate activities emphasizing skill demonstrations, practice opportunities, and specific corrective feedback.

Several limitations should be acknowledged when interpreting these findings. First, the cross-sectional design precludes inferences regarding temporal precedence or causality in PA-MSC relationships. While we have framed PA as a predictor of MSC based on theoretical reasoning, reverse causality is plausible: children with superior motor skills may feel more confident and competent during physical activities, leading to increased PA engagement. Longitudinal and experimental research is needed to disentangle these relationships and identify potential bidirectional effects across development. Randomized controlled trials manipulating PA exposure or motor skill instruction would provide stronger causal evidence regarding these associations. Second, the sample was drawn from a single preschool in urban Medan, potentially limiting generalizability to other Indonesian contexts (rural areas, different socioeconomic strata) or other Southeast Asian populations. Cultural values, educational practices, environmental constraints, and movement traditions vary considerably across the diverse Indonesian archipelago. Multi-site studies incorporating diverse geographic and socioeconomic contexts would strengthen generalizability and enable examination of contextual moderators. Additionally, while our sample size exceeded power requirements for primary analyses, it may have been underpowered to detect smaller effects in subgroup analyses or interaction effects. Third, although accelerometry represents substantial advancement over subjective PA assessment, the technique has limitations. Accelerometers primarily capture ambulatory activities and may underestimate upper-body movements, aquatic activities, and stationary cycling. The intermittent, irregular movement patterns of preschool children pose unique challenges for activity classification algorithms. Furthermore, we employed hip-worn accelerometers following established protocols, but recent evidence suggests wrist-worn placement may improve wear compliance in young children, albeit with trade-offs in measurement validity (Johansson et al., 2016). Future research should explore multi-sensor approaches or direct observation methods to complement accelerometry. Fourth, while the TGMD-3 represents a rigorously validated motor assessment instrument, it captures only a subset of motor competencies relevant to preschool children. Stability and balance skills, fine motor abilities, and movement creativity are not assessed. Additionally, the TGMD-3 evaluates movement process (how skills are performed) rather than product (performance outcomes such as distance or speed), which may not fully capture functional motor capacity relevant to PA engagement. Comprehensive motor assessment batteries incorporating multiple domains would provide richer characterization of motor competence profiles. Fifth, we did not assess potential mediating or moderating variables that may influence PA-MSC relationships. Factors such as perceived motor competence, physical self-concept, parental support for PA, preschool physical environment quality, socioeconomic status, and body composition may moderate the strength or direction of associations (Robinson et al., 2015). Examining such factors would illuminate for whom and under what conditions PA-MSC associations are strongest, informing targeted intervention strategies. For example, environmental constraints or parental attitudes might attenuate PA-MSC relationships in certain subgroups. Finally, we did not differentiate between structured (adult-led) and unstructured (free play) PA or assess specific movement contexts (outdoor vs. indoor, solitary vs. social). Different PA types may have differential relationships with motor skill domains. For instance, structured sports participation might show stronger associations with object control skills, while free outdoor play might relate more strongly to locomotor skills. Future research employing ecological momentary assessment or direct observation could elucidate context-specific PA-MSC relationships.

Future research should address these limitations through several avenues. Longitudinal designs tracking PA and MSC development across multiple time points would clarify temporal dynamics and potential bidirectional relationships. Intervention studies implementing PA promotion programs or motor skill instruction curricula would establish causality and identify effective strategies for enhancing both outcomes. Cross-cultural comparative research across diverse Southeast Asian populations would test generalizability and reveal culturally specific factors influencing PA and motor development. Finally, investigation of potential mediating mechanisms (e.g., movement confidence, enjoyment, perceived competence) and moderating factors (e.g., environmental quality, socioeconomic resources, parental support) would advance theoretical understanding and inform precision intervention approaches.

CONCLUSION

This study provides novel and contextually relevant evidence that daily physical activity, particularly moderate-to-vigorous physical activity (MVPA), is positively and significantly associated with motor skill competence among Indonesian preschool children. Children who accumulated higher levels of MVPA demonstrated superior locomotor and ball skills compared to their less active peers, with effect sizes indicating meaningful practical significance. Importantly, these associations remained robust after controlling for key developmental factors, including biological maturation and gender, and were consistent across multiple analytical approaches. These findings extend existing evidence from predominantly Western contexts and confirm that the physical activity–motor competence relationship is also evident within Southeast Asian early childhood populations.

From a theoretical perspective, the results support developmental models proposing reciprocal and reinforcing relationships between physical activity and motor competence during early childhood. The findings underscore the importance of dynamic, energetic movement experiences as foundational drivers of motor development at this critical life stage. Given that early

motor competence is strongly linked to long-term physical activity participation, physical fitness, and health trajectories, the preschool years represent a sensitive window during which targeted movement experiences may generate enduring benefits. The observed gender disparities in both physical activity engagement and selected motor skill domains further highlight the need to consider sociocultural norms, environmental constraints, and instructional practices that may differentially shape movement opportunities for boys and girls.

Practically, these findings emphasize that physical activity should be treated as a core component of preschool education rather than an optional supplement. Early childhood educators, policymakers, and public health stakeholders are encouraged to ensure that preschool children engage in at least 60 minutes of daily MVPA through a balance of structured instruction and unstructured active play, supported by trained educators and enriched physical environments. Interventions should also intentionally promote girls' participation in vigorous activity and object control skill development to ensure equitable motor learning opportunities. Future research should prioritize longitudinal and experimental designs to establish causal pathways, explore mediating and moderating mechanisms, and test scalable interventions across diverse Indonesian and Southeast Asian contexts. Collectively, this study reinforces the recognition of early childhood physical activity and motor skill development as an educational and public health priority with lifelong implications for physical, social, and emotional wellbeing.

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CONFLICT OF INTEREST

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