Author(s): Kasanen, Maria; Laukkanen, Arto; Niemistö, Donna; Kotkajuuri, Jimi; Luukkainen, Nanne-Mari; Sääkslahti, Arja

Title: Do Fundamental Movement Skill Domains in Early Childhood Predict Engagement in Physical Activity of Varied Intensities Later at School Age? A 3-Year Longitudinal Study

Year: 2023

Version: Published version

Corrected December 1, 2023—see https://doi.org/10.1123/jmld.2023-0070

Journal of Motor Learning and Development, 2023, 11, 424–443
https://doi.org/10.1123/jmld.2023-0004

Human Kinetics
ORIGINAL RESEARCH

Do Fundamental Movement Skill Domains in Early Childhood Predict Engagement in Physical Activity of Varied Intensities Later at School Age? A 3-Year Longitudinal Study

Maria Kasanen, Arto Laukkanen, Donna Niemistö, Jimi Kotkajuuri, Nanne-Mari Luukkainen, and Arja Sääkslahti
Faculty of Sport and Health Sciences, University of Jyväskylä, Jyväskylä, Finland

This study was conducted to determine how total fundamental movement skill (FMS) score and, separately, locomotor skill (LMS), and object control skill scores in children 3–8 years old predicted their specific-intensity physical activity 3 years later. Overall, 441 Finnish children (51.7% female, baseline mean age of 5.6 years) participated in the study. Total FMS, LMS, and object control skill scores were assessed using the Test of Gross Motor Development, third edition. The time spent engaged in physical activity of different intensities (light, moderate, vigorous, moderate-to-vigorous, light-to-vigorous, and sedentary behavior) was determined using accelerometers. A two-level regression model was used in the analysis, considering potential covariates and interactions. The results showed that moderate physical activity, vigorous physical activity, and moderate-to-vigorous physical activity were predicted by the total FMS score ($\beta = 0.177$ to 0.203, $p = .001–.003$) and the LMS score ($\beta = 0.140$ to 0.164, $p = .004–.014$), but not the object control skill score. Moreover, the LMS score inversely predicted sedentary behavior ($\beta = –0.116$, $p = .042$). In conclusion, higher FMS and, specifically, LMS scores seem to predict more engagement in moderate-to-vigorous physical activity and less sedentary behavior over time. However, most of the variance in physical activity remains unexplained.

Keywords: children, infancy, motor development

Laukkanen https://orcid.org/0000-0002-9722-0258
Niemistö https://orcid.org/0000-0002-9198-9437
Kotkajuuri https://orcid.org/0000-0002-4195-8675
Luukkainen https://orcid.org/0000-0002-3204-2905
Sääkslahti https://orcid.org/0000-0003-4354-0990
Kasanen (maria.kasanen@gmail.com) is corresponding author, https://orcid.org/0000-0003-0057-3610

Evidence has shown the health benefits (e.g., bone health, reduced risk for being overweight) of engaging in physical activity (PA) during childhood (Pate et al., 2019; World Health Organization, 2019, 2020). While moderate-to-vigorous physical activity (MVPA) is recommended to promote children's health and well-being, lower levels of activity, such as light physical activity (LPA) are also beneficial (World Health Organization, 2019, 2020). However, the amount of PA that children engage in seems to decrease with age (Cooper et al., 2015; Farooq et al., 2020; Lounassalo et al., 2019), starting at an average age of 7.7 years (Lounassalo et al., 2019). Hence, insufficient PA as a risk factor for noncommunicable diseases and reduced quality of life is a global concern (Guthold et al., 2020; Tucker, 2008). In addition, reducing sedentary behavior (SB) also is important to preventing disease and improving public health (Park et al., 2020). For these reasons, the underlying mechanisms of PA behaviors are important to understand.

Understanding that the underlying mechanisms of PA, such as fundamental movement skills (FMS), start in early childhood is crucial. FMS refer to the performance level of the neural, muscular, biomechanical, and perceptual mechanism involved in movement; the FMS development phase occurs in early childhood (Goodway et al., 2019, pp. 36, 118–119), in children aged eight or younger (UNICEF, 2022). Many theoretical models and frameworks (Brian et al., 2020; Hulteen et al., 2018; Robinson et al., 2015; Seefeldt, 1980; Stodden et al., 2008) have suggested that children with limited FMS in early childhood may have restricted opportunities for engagement in PA later in childhood because they lack the skills necessary to be adequately physically active. Early childhood is considered an effective period for promoting FMS (Brian et al., 2020) and PA behavior, as it can influence children's future PA levels (Goldfield et al., 2012).

According to systematic reviews, evidence of a longitudinal pathway from FMS score to PA level in early childhood (Jones et al., 2020; Xin et al., 2020), as well as across childhood (2–18 years old; Barnett et al., 2021), is limited, and more longitudinal studies on the link between FMS and PA are needed (Barnett et al., 2021; Jones et al., 2020; Xin et al., 2020). FMS include the skill domains of stability, locomotor skills (LMS), and object control skills (OCS; Goodway et al., 2019, pp. 36, 118). Considering the skill domains separately (Barnett et al., 2021) and considering different intensities of PA, including SB (Barnett, Lai, et al., 2016; Barnett, Salmon, & Hesketh, 2016; Xin et al., 2020), may provide a more detailed picture of the relationship between FMS and PA levels. In this study, FMS is defined in terms of gross motor skills, focusing on LMS and OCS.

LMS and OCS may exhibit different longitudinal relationships with PA. LMS enable body movement relative to a fixed point on a surface, from point A to point B (Goodway et al., 2019, pp. 44, 118), which PA often necessitates. Thus, a lack of LMS can hinder PA engagement and increase SB, although physically active children do not necessarily demonstrate decreased SB (Pearson et al., 2014). This also supports considering SB as an independent outcome variable. From the perspective of OCS, Barnett et al. (2009) and Cohen et al. (2014) suggested that OCS are particularly related to MVPA via many games and activities (e.g., soccer), as measured by data gathered through questionnaires as part of a 6-year longitudinal study (baseline mean age = 10.1 years, range = 7.9–11.9 years; Barnett et al., 2009) and through accelerometers worn by students during the school day ($n = 460$, mean age = 8.5 years, $SD = 0.6$) in a cross-sectional study (Cohen et al., 2014).

Based on longitudinal studies initiated in early childhood, the relationship between FMS or skill domains and PA measured by accelerometer does not entirely conform to previous findings. Multiple studies (Bürgi et al., 2011; Duncan et al., 2021; Foulkes et al., 2021; Gu, 2016; Gu et al., 2018; Lima et al., 2017; Melby et al., 2021; Nilsen et al., 2020; Schmutz et al., 2020) have investigated this relationship, beginning in early childhood. The findings have been partly contradictory regarding the pathways from FMS or LMS to PA, and none of the studies provided evidence of a longitudinal relationship from OCS to PA measured by accelerometer.

A few studies (Duncan et al., 2021; Gu, 2016; Gu et al., 2018; Lima et al., 2017) evidenced at least some statistically significant longitudinal pathways from total FMS or skill domain scores to PA measured by accelerometer. Lima et al. (2017) discovered that the total FMS score, measured by Körperkoordinationstest für Kinder, was associated with vigorous PA (VPA) but not with MVPA in Danish children ($n = 298$, baseline mean age = 6.75, $SD = 0.37$) over a 7-year follow-up. Duncan et al. (2021) found that some subtests of LMS, measured by the Test of Gross Motor Development 2nd edition (TGMD-2) at baseline, significantly predicted time spent engaged in MVPA, LPA, and SB 1 year later in British preschoolers ($n = 177$, baseline mean age = 4.46 years, $SD = 0.70$). Gu et al. (2018) observed a positive longitudinal link from FMS total score, measured by PE Metrics related to physical education, to MVPA in school days, as well as a negative relationship to SB in Hispanic children ($n = 141$, baseline mean age = 5.37 years, $SD = 0.485$) over a 1-year follow-up. Another study (Gu, 2016) involving Hispanic children ($n = 256$, baseline mean age = 5.37 years, $SD = 0.48$) also provided evidence of a statistically significant positive longitudinal pathway from FMS to MVPA and SB measured in the same manner used by Gu et al. (2018). This study also revealed that only higher LMS scores predicted a statistically significant greater degree of engagement in MVPA and VPA, and inversely LPA, after controlling for body mass index (BMI; Gu, 2016).

On the other hand, some studies (Bürgi et al., 2011; Foulkes et al., 2021; Melby et al., 2021; Nilsen et al., 2020; Schmutz et al., 2020) did not find a longitudinal association between total FMS or skill domain scores and engagement in various PA intensities. Bürgi et al. (2011) and Schmutz et al. (2020) found no statistically significant relationship when FMS were measured by agility and dynamic balance test (Bürgi et al., 2011) or using the Zurich neuromotor assessment (Schmutz et al., 2020) in Swiss children ($n = 217$–550) aged 2–6 years old (baseline) during a 9- to 12-month follow-up. Moreover, Melby et al. (2021) found no statistically significant relationship between FMS measured by Körperkoordinationstest für Kinder at 6 years old and MVPA at 9 and 13 years ($n = 654$). At the same time, Foulkes et al. (2021) found no longitudinal relationship between FMS, LMS, or OCS measured by TGMD-2 and MVPA in British preschoolers ($n = 75$, baseline mean age = 4.5 years, $SD = 0.6$) over a 5-year follow-up. Similarly, Nilsen et al. (2020) reported finding no longitudinal relationship based on an examination of LMS and OCS measured by the TGMD-3 as predictors, with PA intensity and SB as outcome variables in Norwegian children ($n = 230$, baseline mean age = 4.7 years, $SD = 0.9$) over a 2-year follow-up.

The related literature lacks comprehensive longitudinal studies examining pathways from total FMS or skill domains scores to PA of varied intensities in early childhood; furthermore, existing results are contradictory. The current study aimed to provide a more accurate picture of the longitudinal pathways from FMS scores to accelerometer-measured PA levels utilizing skill domains and multiple PA intensities (light-to-vigorous PA [LVPA], LPA, moderate PA [MPA], MVPA, VPA, and SB), considering the effect of age (Barnett, Lai, et al., 2016; Farooq et al., 2020; Lounassalo et al., 2019; Valentini et al., 2022), gender (Barnett, Lai, et al., 2016; Ricardo et al., 2022; Zheng et al., 2022), and BMI (Jago et al., 2020; Lopes et al., 2021). This study was guided by two research questions that asked how total FMS score and, separately, LMS and OCS scores in children 3–8 years old predict time spent engaged in PA at different intensities 3 years later. Social-level factors, like school, may interact with individual-level factors to determine children's PA (Duncan et al., 2004); this is considered in a two-level regression analysis (Hox et al., 2010) in this study. Despite contradictory research results, the authors hypothesized a positive longitudinal pathway from total FMS score to time spent engaged in various PA intensities based on previous literature (Brian et al., 2020; Hulteen et al., 2018; Robinson et al., 2015; Seefeldt, 1980; Stodden et al., 2008) and research findings (Gu, 2016; Gu et al., 2018; Lima et al., 2017). The authors also hypothesized that LMS may have a statistically significant longitudinal relationship with engagement in various PA intensities according to previous research results (Duncan et al., 2021; Gu, 2016), as opposed to the link to OCS, of which no evidence was found in previous studies (Duncan et al., 2021; Foulkes et al., 2021; Gu, 2016; Nilsen et al, 2020).

Materials and Methods

Design and Participants

The baseline (T1) data for this longitudinal study were derived from the Skilled Kids study (2015–2016, $n = 1{,}238$), which was based on a geographic cluster randomization of childcare centers in Finland (Laukkanen et al., 2018). Of the children who participated in the measurement at T1, only 950 were contacted in the follow-up (T2) for the Active Family study (2018–2020) because complete data on the main study variables of the Active Family study (parental support for child's PA and child's outdoor time on weekdays and weekends) were available at T1. Among these 950 children, 675 (from 97 schools) participated in the follow-up assessment, and only for this group did researchers have permission to combine T1 and T2 data. The difference between the contacted and participating children (275 out of 950) was acceptable (29%) from the bias perspective in the follow-up (Kristman et al., 2004).

However, out of these 675 participants, LMS and OCS levels were measured in 592 children. Acceptable PA measurements (at least 10 hr recording time per day on at least two weekdays and one weekend day) were missing for 144 participants, and data on at least one other model-involved variable were missing for seven children. All participants with available results for all variables used in the analysis were included in the study ($n = 441$, 46.4% of initial sample of T2, girls = 228 [51.7%]; at T1: mean age = 5.6 years, $SD = 1.1$, in 37 childcare centers; at T2: mean age = 8.8 years, $SD = 1.1$, in 52 schools). The data were missing completely at random (Little's missing completely at random (MCAR) test chi-square = 31.983, $df = 22$, $p = .078$), considering all model-involved variables. This indicates that the model included observations ($n = 441$) represent a random subset of all the observations ($n = 675$) and that the distributions of the missing and observed values will be comparable (Bhaskaran & Smeeth, 2014). Thus, the complete case analysis is valid (Ross et al., 2020).

Both T1 and T2 studies received ethical approval from the Ethics Committee of the University of Jyväskylä, on October 30, 2015, for T1 and on June 28, 2018, for T2. Participation was voluntary, and appropriate permissions were obtained to conduct the research from the parents for their own and their children's participation before the beginning of data collection at both T1 and T2.

Measurements

Fundamental Movement Skills

FMS were measured using the TGMD-3 (Ulrich, 2013, 2019), a process-oriented measure developed for children aged 3–11 years old, which included six LMS subtests that produced a maximum total of 46 points and examined the following skills: run (0–8 points), gallop (0–8), hop (0–8), skip (0–6), horizontal jump (0–8), and slide (0–8). OCS levels were measured by seven subtests (two-hand strike of a stationary ball [0–10 points], one-hand forehand strike [0–8], one-hand stationary dribble [0–6], two-hand catch [0–6], kicking a stationary ball [0–8], overhand throw [0–8], and underhand throw [0–8]) for a maximum total score of 54 points. Total FMS score was defined by the gross motor index of the TGMD-3 measure, reflecting a sum of the LMS and OCS subtest scores; the maximum score was 100 points (Ulrich, 2013, 2019).

The TGMD-3 evaluates qualitative information on children's total FMS level and, separately, their LMS and OCS levels. The qualitative evaluation of each skill is based on three to five performance criteria, depending on the skill (Ulrich, 2013, 2019). Observing performance with the naked eye is effective for investigating FMS levels (Goodway et al., 2019, p. 36). Each performance is scored according to the defined criteria by a trained observer. If the criterion is met, one point is allocated instead of zero, and vice versa. Children perform each activity twice. The sum of the scores from these two trials for each performance criterion constitutes the total score for the skill (Ulrich, 2013, 2019).

The TGMD-3 is recommended for FMS testing because of low cost, feasibility, and strong psychometric properties. According to one meta-analysis, the interrater reliability of TGMD-3 was above 0.9 in about 70% of the reported statistics (19 studies; Rey et al., 2020). Regarding data collection for the current study, the interrater reliability was determined to be good (interclass correlation = .88, 95% confidence interval [.85, .92]) based on the performance of 167 children before data collection in T1 (Niemistö et al., 2019). According to the meta-analysis, the intrarater reliability of the TGMD-3 was greater than 0.9 in 85% of reported statistics ($n = 13$ studies). Moreover, the internal consistency of the TGMD-3 was between acceptable and excellent (Cronbach's alpha .7–.9), and test–retest reliability was over 0.8 (Rey et al., 2020).

Accelerometer-Based Physical Activity Intensities

An accelerometer can reliably measure the PA of children (Pate et al., 2010). PA was measured at T2 using triaxial accelerometers (UKK RM-42, UKK

Terveyspalvelut Oy). Participants were instructed to attach the accelerometer to the right side of the waist with an elastic belt for seven consecutive days during waking hours, excluding sick days. They were further instructed to remove the accelerometer at bedtime and during showering, saunas, and swimming. Accelerometer data collected between 6 a.m. and 10 p.m. were included for analysis. Nonwear time was determined as a mean amplitude deviation (MAD) of the acceleration below 0.02*g* for 60-min periods. An accelerometer recording time of at least 10 hr per day, which is a recommended criterion, was considered acceptable (Migueles et al., 2017). Valid accelerometer data for at least two weekdays (on average 4.2 weekdays) and one weekend day (on average 1.9 weekend days) was an inclusion criterion, as this has been shown to provide an acceptable (62%) level of reliability (Penpraze et al., 2006).

MATLAB software was used for the accelerometer data analysis. Accelerometer data (100 Hz) were classified according to MAD based on nonoverlapping epochs of 5-s periods. The MAD is considered suitable for analyzing PA intensity for children (Aittasalo et al., 2015; Gao et al., 2019). Moreover, MAD cut-points in the analysis were under 29 for SB, 29 for LPA, 338 for MPA, and 604 for VPA (Aittasalo et al., 2015). The sum of the time spent engaged in LPA, MPA, and VPA constitutes the LVPA.

Gender, Age, Body Mass Index, and Time Between Measurements

Parents reported the child's gender (options: girl or boy) and date of birth by completing a questionnaire at T1. The exact age of each child was calculated using the date of birth and the test date. BMI-for-age was calculated using weight (seca 877, seca GmbH & Co. KG.) and height (HM200P, Charder Electronic Co., Ltd.) measured directly to the nearest decimal. BMI *SD* scores were calculated according to Finnish children's national standards (Saari et al., 2011). The time between baseline and follow-up measurements (T1–T2) was calculated as the difference between measurement dates in T1 and T2.

Data Analyses

The predictive effect of total FMS score and of LMS and OCS scores on time spent engaged in PA of varied intensities was investigated using two-level regression analyses (Hox et al., 2010) due to data clustering. The two-level hierarchical data structure included the participants (first level) nested within the schools (second level). Individual-level predictive variables in T1 were measured in childcare centers, which is why school level predictive variables were not used in the longitudinal analysis. Participants were nested in 52 schools (on average, 5.3 students per school, range 1–23) in T2.

The predictor variables for the analyses were total FMS score or LMS and OCS scores. In addition to the main effects of age and gender, interactions between total FMS score, LMS, and OCS with gender (total FMS score-by-gender, LMS-by-gender interaction, OCS-by-gender interaction) and age (total FMS score-by-age, LMS-by-age interaction, OCS-by-age interaction) also were used as predictor variables. Interactions were used to analyze gender and age differences in the models. If interactions were statistically significant, more detailed analyses were performed. Otherwise, the interactions were removed from the analysis, and only the main effects were reported. BMI *SD* scores were used as a covariate. All these variables were measured at baseline (T1). Also, the time between measurements (T1–T2, mean 3.2 years, range 2.39–4.55 years) was used as a covariate in the analysis due to the considerable variability between participants. The outcome variables LVPA, LPA, MPA, MVPA, VPA, and SB were measured, on average, 3 years later (T2).

Descriptive statistics and analyses were performed using SPSS (version 28) software. Differences between the means for girls and for boys were tested with the Mann–Whitney *U* test. The statistical significance level was set at $p < .05$ for all analyses. All outcome variables were tested for normality, and VPA was Box-Cox power transformed due to skewness. Standardized values of the variables were used in the analyses.

The two-level regression analyses were executed by linear mixed model using restricted maximum likelihood estimation and Satterthwaite approximation. If school level was not statistically significant in the two-level regression analysis, a linear regression analysis was performed.

Results

The descriptive statistics of the study population are presented in Table 1. Gender differences were found in the total FMS scores ($p = .037$), LMS scores, OCS scores, and PA intensities ($p < .001$). Girls obtained higher LMS scores, and they engaged in more LPA. Correspondingly, boys obtained higher total FMS and OCS scores and engaged in more MPA, MVPA, and VPA.

The school level, according to the interclass correlation of the null model, explained 8.0% ($p = .040$) of the variance for LVPA, 11.4% ($p = .020$) for LPA, 13.3% ($p = .014$) for MPA, 13.8% ($p = .010$) for MVPA, and 12.3% ($p = .004$) for VPA. School level results were not statistically significant for SB (interclass correlation = .041, $p = .224$); a linear regression analysis was performed for SB.

The interaction of total FMS score with gender was statistically significant ($\beta = -0.177$, $p = .044$) only in the pathway from total FMS score to LPA. Thus, the analyses were performed separately with both genders as a reference group (coded 0). Therefore, the main effects of the total FMS score could be obtained for both genders. Despite this, the main effect of the total FMS score did not statistically significantly predict LPA (girls: $\beta = 0.060$, $p = .443$; boys: $\beta = -0.117$, $p = .087$; see Table 2). Gender and its interactions are reported in Table 2 with girls as the reference group (girls = 0). For boys, the estimates for gender and its interactions were the same, except negative values changed to positive. Interactions of total FMS score, LMS score, and OCS score with gender or age were not statistically significant ($p = .117$–$.856$) regarding time spent engaged in other levels of PA intensity. Thus, only the results of the main effects are reported. Results for the pathways from total FMS score to LVPA, MPA, MVPA, and VPA are presented in Table 3, and results on the association between LMS and OCS with the same PA intensities are conveyed in Table 4. The SB results are presented in Tables 5 and 6.

Table 1 Descriptive Statistics

Variable	*M*	*SD*	Gender differences (*p*)
Age (years)	5.60	1.05	.484
Girls	5.57	1.03	
Boys	5.62	1.08	
Body mass index SDS	0.19	1.05	.443
Girls	0.22	1.13	
Boys	0.16	0.96	
T1–T2 (years)	3.22	0.37	.935
Girls	3.22	0.35	
Boys	3.23	0.39	
Total FMS score (0–100 points)	54.94	13.85	**.037**
Girls	53.75	12.57	
Boys	56.22	15.03	
Locomotor skills (0–46 points)	28.95	7.33	**<.001**
Girls	30.23	6.88	
Boys	27.57	7.57	
Object control skills (0–54 points)	26.00	8.71	**<.001**
Girls	23.52	7.59	
Boys	28.65	9.06	
Light-to-vigorous PA (min/day)	452.10	60.74	.993
Girls	452.19	60.25	
Boys	452.01	61.41	
Light PA (min/day)	282.44	44.55	**<.001**
Girls	293.45	42.25	
Boys	270.66	44.03	
Moderate PA (min/day)	156.18	36.01	**<.001**
Girls	147.23	33.44	
Boys	165.76	36.27	
Moderate-to-vigorous PA (min/day)	169.66	41.89	**<.001**
Girls	158.74	38.62	
Boys	181.35	42.18	
Vigorous PA (min/day)	13.48	10.50	**<.001**
Girls	11.51	9.50	
Boys	15.59	11.11	
Sedentary behavior (min/day)	334.02	59.22	.482
Girls	336.24	60.52	
Boys	331.65	57.84	

Note. *p* values of gender differences under .05 are shown in bold. SDS = standard deviation score; T1–T2 = time between baseline (T1) and follow-up (T2) measurements; FMS = fundamental movement skills; PA = physical activity.

Table 2 Results of Pathway From Total FMS Score to Light Physical Activity

Variables	Light physical activity		
	Estimate	***SE***	***p***
Total FMS score			
Girls	0.061	0.078	.434
Boys	–0.117	0.068	.087
Total FMS score × Gender[a]	–0.178	0.088	**.043**
Gender[b]	–0.479	0.087	**<.001**
Age	–0.252	0.059	**<.001**
T1–T2	–0.164	0.049	**.001**
Body mass index SDS	–0.016	0.044	.721
$R^2 = .115$			

Note. Statistically significant (p value under .05) longitudinal relationships are shown in bold. FMS = fundamental movement skills; T1–T2 = time between baseline (T1) and follow-up (T2) measurements; SDS = standard deviation scores.
[a]Interaction is reported with girls as the reference group. [b]Gender is reported with girls as the reference group.

The pathways from total FMS score to MPA (β = 0.177, $p = .003$) and VPA (β = 0.201, $p < .001$), separately, and to MVPA (β = 0.203, $p < .001$) were statistically significant. Of the skill domains, LMS scores predicted PA intensities similarly to the total FMS scores. LMS predicted, with statistical significance, MPA (β = 0.140, $p = .014$), VPA (β = 0.156, $p = .008$), and MVPA (β = 0.164, $p = .004$) and, inversely, SB (β = –0.116, $p = .042$). The pathways from OCS to PA intensities were not statistically significant (p = .291–.991).

The main effects of baseline age and gender predicted time spent engaged in PA of various intensities 3 years later. Time spent engaged in PA at different intensities decreased (β = –0.419 to –0.170, p = .001–.004) with age, except with respect to LVPA (β = 0.001 to 0.039, p = .703–.987). On the other hand, SB increased statistically significantly with age (β = –0.398 to 0.408, $p < .001$). Gender was a statistically significant predictor of time spent engaged in PA of varied intensities (β = –0.477 to 0.559, $p < .001$) except LVPA (β = 0.001 to 0.039, p = .703–.987) and SB (β = –0.139 to –0.079, p = .168–.372). In addition, BMI *SD* scores predicted a greater degree of SB (β = 0.095 to 0.099, p = .027–.034). T1–T2 was a statistically significant covariate and predicted a lower amount of LVPA (β = –0.196, $p < .001$), LPA (β = –0.162, $p = .002$), and MVPA (β = –0.116 to –0.115, p = .033–.034) and a higher rate of SB (β = 0.176, $p < .001$).

The two-level regression models for total FMS score explained overall 7.8%, 11.5%, 11.4%, 11.8%, and 5.1% of the variability in LVPA, LPA, MPA, MVPA, and VPA, respectively. Results were similar in the model of skill domains, LMS, and OCS, which explained overall 7.9%, 10.3%, 11.2%, 11.8%, and 5.1% of the variability in LVPA, LPA, MPA, MVPA, and VPA, respectively. The linear regression model for total FMS score explained 14.3%, and the model for the LMS and OCS domains explained 14.4% of the variability in SB.

Table 3 Results of Two-Level Regression Analysis for Models of Pathways From Total FMS Score to PA Intensities

	Model 1			Model 2			Model 3			Model 4		
	Light-to-vigorous PA			Moderate PA			Moderate-to-vigorous PA			Vigorous PA		
Variable	**Estimate**	***SE***	***p***	**Estimate**	***SE***	***p***	**Estimate**	***SE***	***p***	**Estimate**	***SE***	***p***
Total FMS score	0.112	0.059	.057	0.177	0.058	**.003**	0.203	0.058	**<.001**	0.201	0.060	**<.001**
Gender	0.001	0.089	.987	0.489	0.088	**<.001**	0.502	0.087	**<.001**	0.312	0.090	**<.001**
Age	–0.419	0.059	**<.001**	–0.328	0.060	**<.001**	–0.323	0.060	**<.001**	–0.179	0.062	**.004**
T1–T2	–0.196	0.046	**<.001**	–0.116	0.054	**.033**	–0.124	0.054	**.023**	–0.102	0.055	.067
Body mass index SDS	–0.042	0.044	.340	–0.036	0.044	.412	–0.044	0.043	.311	–0.047	0.045	.298
R^2		.078			.114			.118			.051	

Note. Statistically significant (*p* value under .05) longitudinal relationships are shown in bold. PA = physical activity; FMS = fundamental movement skills; T1–T2 = time between baseline (T1) and follow-up (T2) measurements; SDS = standard deviation scores.

Table 4 Results of Two-Level Regression Analysis for Models of Pathways From Locomotor Skills and Object Control Skills to PA Intensities

	Model 1			Model 2			Model 3			Model 4			Model 5		
	Light-to-vigorous PA			Light PA			Moderate PA			Moderate-to-vigorous PA			Vigorous PA		
Variable	**Estimate**	***SE***	***p***	**Estimate**	***SE***	***p***	**Estimate**	***SE***	***p***	**Estimate**	***SE***	***p***	**Estimate**	***SE***	***p***
Locomotor skills	0.096	0.057	.092	–0.022	0.057	.701	0.140	0.057	**.014**	0.164	0.057	**.004**	0.156	0.059	**.008**
Object control skills	0.029	0.065	.651	–0.030	0.064	.645	0.059	0.065	.362	0.065	0.064	.310	0.070	0.067	.291
Gender	0.039	0.101	.703	–0.476	0.100	**<.001**	0.536	0.100	**<.001**	0.559	0.099	**<.001**	0.363	0.103	**<.001**
Age	–0.412	0.059	**<.001**	–0.249	0.060	**<.001**	–0.320	0.061	**<.001**	–0.314	0.060	**<.001**	–0.170	0.062	**.006**
T1–T2	–0.196	0.046	**<.001**	–0.166	0.049	**<.001**	–0.115	0.054	**.034**	–0.123	0.054	**.024**	–0.101	0.055	.069
Body mass index SDS	–0.040	0.045	.369	–0.015	0.044	.740	–0.032	0.044	.459	–0.040	0.044	.359	–0.043	0.045	.339
R^2		.079			.103			.112			.118			.051	

Note. Statistically significant (*p* value under .05) longitudinal relationships are shown in bold. PA = physical activity; T1–T2 = time between baseline (T1) and follow-up (T2) measurements; SDS = standard deviation scores.

Table 5 Results of Linear Regression Analysis for Pathway From Total FMS Score to Sedentary Behavior

Variable	Estimate	*SE*	*p*
Total FMS score	–0.107	0.059	.070
Gender	–0.079	0.089	.372
Age	0.408	0.059	**<.001**
T1–T2	0.176	0.045	**<.001**
Body mass index SDS	0.099	0.044	**.027**
$R^2 = .152$, adjusted $R^2 = .143$			
$F(5, 435) = 15.631$, $p < .001$, SEE = 0.926			

Note. Statistically significant (*p* value under .05) longitudinal relationships are shown in bold. FMS = fundamental movement skills; T1–T2 = time between baseline (T1) and follow-up (T2) measurements; SDS = standard deviation scores; SEE = standard error of the estimate.

Table 6 Results of Linear Regression Analysis for Pathway From Locomotor Skills and Object Control Skills to Sedentary Behavior

Variable	Estimate	*SE*	*p*
Locomotor skills	–0.116	0.057	**.042**
Object control skills	–0.001	0.065	.991
Gender	–0.139	0.101	.168
Age	0.398	0.059	**<.001**
T1–T2	0.176	0.045	**<.001**
Body mass index SDS	0.095	0.045	**.034**
$R^2 = .155$, adjusted $R^2 = .144$			
$F(6, 434) = 13.302$, $p < .001$, SEE = 0.925			

Note. Statistically significant (*p* value under .05) longitudinal relationships are shown in bold. T1–T2 = time between baseline (T1) and follow-up (T2) measurements; SDS = standard deviation scores; SEE = standard error of the estimate.

Discussion

This study was designed to investigate how total FMS score, and the LMS and OCS domains in children 3–8 years old predicted time spent engaged in PA at different intensities 3 years later. The results showed that higher total FMS scores and, especially, higher LMS scores predicted more time spent engaged in MPA, VPA, and MVPA. In addition, higher LMS scores inversely predicted SB, while OCS scores did not statistically significantly predict PA of varied intensities. In this study, no age or gender differences were uncovered in the longitudinal relationships between FMS and PA based on interactions, excluding the pathway from FMS to LPA. The results of this study indicate that higher LMS scores, especially, may predict more engagement in MVPA and less SB over time. However, most of the variance in PA remains unexplained; furthermore, other variables also play a significant role in time spent engaged in PA at varying intensities.

As noted, the relationships between FMS or skill domains and PA intensities do not seem straightforward (Barnett, Lai, et al., 2016). The findings of this research support our hypotheses and are consistent with existing theoretical frameworks and models. FMS level may be an underlying variable influencing PA (Brian et al., 2020; Hulteen et al., 2018; Robinson et al., 2015; Seefeldt, 1980; Stodden et al., 2008). However, the longitudinal relationship appears tenuous, as previous studies have shown (Barnett et al., 2021; Duncan et al., 2021; Gu, 2016; Gu et al., 2018; Lima et al., 2017), and the results are indeterminate because some studies have not demonstrated a statistically significant longitudinal association between these variables (Barnett et al., 2021; Bürgi et al., 2011; Foulkes et al. 2021; Melby et al., 2021; Nilsen et al., 2020; Schmutz et al., 2020). An individual's current FMS level has been proposed as having a stronger relationship with PA than the previous FMS level (Nilsen et al., 2020), as FMS are known to develop (Barnett, Lai, et al., 2016), and PA is known to decrease with age (Farooq et al., 2020; Lounassalo et al., 2019). Some studies (Gu, 2016; Gu et al., 2018), including the current investigation, have not been able to consider current FMS or PA levels. At the same time, a statistically significant longitudinal pathway from PA to FMS has been evidenced (Estevan et al., 2022; Lima et al., 2017; Nilsen et al., 2020; Reyes et al., 2019).

The use of skill domains and various PA intensities in analyses may provide more detailed information on the longitudinal pathway from FMS to PA, as earlier studies have suggested (Barnett, Lai, et al., 2016; Barnett, Salmon, & Hesketh, 2016; Jones et al., 2020; Xin et al., 2020). The use of skill domains also enables consideration of the influence of other variables, such as BMI (Barnett, Lai, et al., 2016) and gender (Zheng et al., 2022), that may be related to LMS and OCS in various ways. Additionally, the results of this study are consistent with previous longitudinal research findings regarding relationships between PA and both LMS and OCS (Barnett et al., 2021; Duncan et al., 2021; Gu, 2016) using PA measured by accelerometer. These studies have demonstrated a longitudinal pathway from LMS to various PA intensities, including SB, but not for the pathway from OCS to PA, findings that mirror those of this study. This result is partially inconsistent with those of other studies (Foulkes et al., 2021; Nilsen et al., 2020), based on which no statistically significant longitudinal pathways were reported, even from LMS to varying PA intensities.

Although OCS has been suggested as being associated with many games that involve MVPA (Barnett et al., 2009; Cohen et al., 2014), some activities can be too competitive, making them less enjoyable for children (Allender et al., 2006). This may further diminish the significance of the path from OCS to MVPA. While OCS have been linked to MVPA, particularly during school breaks (Cohen et al., 2014), time spent outside of school hours, such as during journeys between home and school, may be tied to a greater amount of MVPA (Rainham et al., 2012). The importance of LMS in the context of PA, including SB, may increase, and the significance of OCS may decrease when examining PA throughout the day. Over 80% of Finnish primary school children actively travel (e.g., walking or biking) to and from school (Turunen et al., 2023, p. 79), which may emphasize the positive relationship from LMS to MVPA and the inverse association with SB uncovered in this study. Also, Cohen et al. (2014) found that LMS were statistically significant predictors of total and after-school MVPA but not for MVPA during school breaks.

In addition to active travel to and from school, the most common physical activities Finnish children engage in during their free time are football, skating, ice hockey, skiing, swimming, cycling, and frisbee golf, depending on the time of year (Martin et al., 2023, p. 18). Some of these activities require OCS; however, LMS is necessary for all of them. This further emphasizes the importance of LMS, as many common exercises and daily activities are performed using LMS.

Instead of the statistically insignificant results of interactions with age or gender and FMS or skill domain score in this study and previous studies (Nilsen et al., 2020; Schmutz et al., 2020), the main effects of age and gender on PA appear significant in childhood (Cooper et al., 2015). Also in this study, the standardized coefficients of age and gender are generally higher than the standardized coefficients of FMS or skill domains. Schmutz et al. (2018) stated that gender and age are the most important nonmodifiable individual-level variables related to PA levels. Boys engaged in more higher intensity PA (Brazo-Sayavera et al., 2021; Ricardo et al., 2022) and exhibited lower degrees of SB (Brazo-Sayavera et al., 2021; Prince et al., 2020) than girls, while the amount of PA decreases with age, as has been observed in previous studies (Cooper et al., 2015; Farooq et al., 2020; Lounassalo et al., 2019). SB seems to increase with age from childhood to adolescence (Rubín et al., 2022). When many biological, psychological, sociocultural, and environmental variables affect PA (Li & Moosbrugger, 2021) in addition to the main effect of age and gender, the share of total FMS score or skill domains remains small.

Comparison of the relationships found between FMS and PA in prior research results is complicated by the variability of the target group (e.g., age, gender), the difference in the measurements of FMS and PA, and variations in the follow-up periods (Barnett et al., 2021; Jones et al., 2020; Xin et al., 2020). The baseline ages of participants ranged from 2 to 7 years, follow-up periods spanned from 9 months to 7 years, and six tests were used to measure FMS in studies investigating the longitudinal pathways from FMS or skill domains to PA beginning in early childhood (Bürgi et al., 2011; Duncan et al., 2021; Foulkes et al., 2021; Gu, 2016; Gu et al., 2018; Lima et al., 2017; Melby et al., 2021; Nilsen et al., 2020; Schmutz et al., 2020). Moreover, process- and product-oriented measures of FMS are not interchangeable because they assess different aspects of FMS (Palmer et al., 2021). However, both process- (Duncan et al., 2021; Foulkes et al., 2021; Gu, 2016; Gu et al., 2018; Nilsen et al., 2020; Schmutz et al., 2020) and product-oriented (Bürgi et al., 2011; Lima et al., 2017; Melby et al., 2021; Schmutz et al., 2020) measurements of FMS or skill domains seem to produce contradictory results. In addition, Nilsen et al. (2020) evaluated LMS and OCS levels using the TGMD-3, like in the current study; nevertheless, the results were contradictory.

The strength of this study was in examining longitudinal data on young children in early childhood, with an average 3-year follow-up, and the use of two-level regression analysis as a statistical method. In addition, we used total FMS score, skill domains, and PA intensities to explore more specifically the pathway from FMS to PA. Also, the interaction between total FMS score, LMS level, and OCS level with gender and age were used as predictor variables to obtain a more accurate picture.

However, this study also has its limitations. One major limitation is that PA was not assessed at T1. Also, despite the use of high-quality measures in assessing accelerometer-based PA, these measures have their own challenges. For instance, they do not account for water activities, as the device must be removed before entering the water. Moreover, measuring PA over two weekdays and one weekend day may not provide an accurate representation of habitual PA. Another noted limitation of accelerometers is their inability to accurately measure the quality, context, and type of PA (Barnett, Salmon, & Hesketh, 2016). The dropout factor constitutes a final limitation of the current study, as some of the participants at T1 did not participate in the follow-up phase of the research at T2. However, this is a rather frequent phenomenon in longitudinal studies that are based on voluntary participation (Hogan et al., 2004). To conclude, the lacking data were missing completely at random. In total, 675 children provided consent to combine data from T1 and T2, prohibiting the comparison of the analyzed sample ($n = 441$) with the Skilled Kids study sample ($n = 1{,}238$).

More studies are needed in the future that examine the longitudinal relationship between FMS and PA from early childhood to adolescence and beyond, with comparable measures if possible. Moreover, future longitudinal studies should examine different reciprocal aspects of the relationship between FMS and PA with the same study population at multiple time points, which makes the growth curve analysis method possible. The use of skill domains and PA intensities, including SB, in future studies can provide a more detailed picture of this relationship. Also, by comparing process- and product-oriented measurements, a more detailed relationship between FMS and PA can be obtained.

Acknowledgments

Research data collection for the Skilled Kids study and the Active Family study was funded by the Finnish Ministry of Education and Culture (OKM/48/626/2014 and OKM/59/626/2017). We thank all participants and their parents for their involvement in the study. We also thank those who participated in the collection of the data.

References

Aittasalo, M., Vähä-Ypyä, H., Vasankari, T., Husu, P., Jussila, A.-M., & Sievänen, H. (2015). Mean amplitude deviation calculated from raw acceleration data: A novel method for classifying the intensity of adolescents' physical activity irrespective of accelerometer brand. *BMC Sports Science, Medicine and Rehabilitation, 7*(1), Article 18. https://doi.org/10.1186/s13102-015-0010-0

Allender, S., Cowburn, G., & Foster, C. (2006). Understanding participation in sport and physical activity among children and adults: A review of qualitative studies. *Health Education Research, 21*(6), 826–835. https://doi.org/10.1093/her/cyl063

Barnett, L.M., Lai, S.K., Veldman, S.L.C., Hardy, L.L., Cliff, D.P., Morgan, P.J., Zask, A., Lubans, D.R., Shultz, S.P., Ridgers, N.D., Rush, E., Brown, H.L., & Okely, A.D. (2016). Correlates of gross motor competence in children and adolescents: A systematic review and meta-analysis. *Sports Medicine, 46*(11), 1663–1688. https://doi.org/10.1007/s40279-016-0495-z

Barnett, L.M., Salmon, J., & Hesketh, K.D. (2016). More active pre-school children have better motor competence at school starting age: An observational cohort study. *BMC Public Health, 16*(1), Article 1068. https://doi.org/10.1186/s12889-016-3742-1

Barnett, L.M., van Beurden, E., Morgan, P., Brooks, L., & Beard, J. (2009). Childhood motor skill proficiency as a predictor of adolescent physical activity. *Journal of Adolescent Health, 44*(3), 252–259. https://doi.org/10.1016/j.jadohealth.2008.07.004

Barnett, L.M., Webster, E.K., Hulteen, R.M., De Meester, A., Valentini, N.C., Lenoir, M., Pesce, C., Getchell, N., Lopes, V.P., Robinson, L.E., Brian, A., & Rodrigues, L.P. (2021). Through the looking glass: A systematic review of longitudinal evidence, providing new insight for motor competence and health. *Sports Medicine, 52,* 875–920. https://doi.org/10.1007/s40279-021-01516-8

Bhaskaran, K., & Smeeth, L. (2014). What is the difference between missing completely at random and missing at random? *International Journal of Epidemiology, 43*(4), 1336–1339. https://doi.org/10.1093/ije/dyu080

Brazo-Sayavera, J., Aubert, S., Barnes, J.D., González, S.A., & Tremblay, M.S. (2021). Gender differences in physical activity and sedentary behavior: Results from over 200,000 Latin-American children and adolescents. *PLoS One, 16*(8), Article e0255353. https://doi.org/10.1371/journal.pone.0255353

Brian, A., Getchell, N., True, L., De Meester, A., & Stodden, D.F. (2020). Reconceptualizing and operationalizing Seefeldt's proficiency barrier: Applications and future directions. *Sports Medicine, 50*(11), 1889–1900. https://doi.org/10.1007/s40279-020-01332-6

Bürgi, F., Meyer, U., Granacher, U., Schindler, C., Marques-Vidal, P., Kriemler, S., & Puder, J.J. (2011). Relationship of physical activity with motor skills, aerobic fitness and body fat in preschool children: A cross-sectional and longitudinal study (Ballabeina). *International Journal of Obesity, 35*(7), 937–944. https://doi.org/10.1038/ijo.2011.54

Cohen, K.E., Morgan, P.J., Plotnikoff, R.C., Callister, R., & Lubans, D.R. (2014). Fundamental movement skills and physical activity among children living in low-income communities: A cross-sectional study. *International Journal of Behavioral Nutrition and Physical Activity, 11*(1), Article 49. https://doi.org/10.1186/1479-5868-11-49

Cooper, A.R., Goodman, A., Page, A.S., Sherar, L.B., Esliger, D.W., van Sluijs, E.M., Andersen, L.B., Anderssen, S., Cardon, G., Davey, R., Froberg, K., Hallal, P., Janz, K.F., Kordas, K., Kreimler, S., Pate, R.R., Puder, J.J., Reilly, J.J., Salmon, J., … Ekelund, U. (2015). Objectively measured physical activity and sedentary time in youth: The International Children's Accelerometry Database (ICAD). *International Journal of Behavioral Nutrition and Physical Activity, 12*(1), Article 113. https://doi.org/10.1186/s12966-015-0274-5

Duncan, M.J., Hall, C., Eyre, E., Barnett, L.M., & James, R.S. (2021). Pre-schoolers fundamental movement skills predict BMI, physical activity, and sedentary behavior: A longitudinal study. *Scandinavian Journal of Medicine and Science in Sports, 31*(1), 8–14. https://doi.org/10.1111/sms.13746

Duncan, S.C., Duncan, T.E., Strycker, L.A., & Chaumeton, N.R. (2004). A multilevel approach to youth physical activity research. *Exercise and Sport Sciences Reviews, 32*(3), 95–99. https://doi.org/10.1097/00003677-200407000-00004

Estevan, I., Clark, C., Molina-García, J., Menescardi, C., Barton, V., & Queralt, A. (2022). Longitudinal association of movement behaviour and motor competence in childhood: A structural equation model, compositional, and isotemporal substitution analysis. *Journal of Science and Medicine in Sport, 25*(8), 661–666. https://doi.org/10.1016/j.jsams.2022.05.010

Farooq, A., Martin, A., Janssen, X., Wilson, M.G., Gibson, A.-M., Hughes, A., & Reilly, J.J. (2020). Longitudinal changes in moderate-to-vigorous-intensity physical activity in children and adolescents: A systematic review and meta-analysis. *Obesity Reviews, 21*(1), Article e12953. https://doi.org/10.1111/obr.12953

Foulkes, J.D., Knowles, Z., Fairclough, S.J., Stratton, G., O'Dwyer, M.V., & Foweather, L. (2021). Is foundational movement skill competency important for keeping children physically active and at a healthy weight? *International Journal of Environmental Research and Public Health, 19*(1), Article 105. https://doi.org/10.3390/ijerph19010105

Gao, Y., Haapala, E.A., Vanhala, A., Sääkslahti, A., Rantakokko, M., Laukkanen, A., Pesola, A.J., Rantalainen, T., & Finni, T. (2019). Sedentary thresholds for accelerometry-based mean amplitude deviation and electromyography amplitude in 7–11 years old children. *Frontiers in Physiology, 10,* Article 997. https://doi.org/10.3389/fphys.2019.00997

Goldfield, G.S., Harvey, A., Grattan, K., & Adamo, K.B. (2012). Physical activity promotion in the preschool years: A critical period to intervene. *International Journal of Environmental Research and Public Health, 9*(4), 1326–1342. https://doi.org/10.3390/ijerph9041326

Goodway, J.D., Ozmun, J.C., & Gallahue, D.L. (2019). *Understanding motor development: Infants, children, adolescents, adults* (8th ed.). Jones & Bartlett Learning.

Gu, X. (2016). Fundamental motor skill, physical activity, and sedentary behavior in socioeconomically disadvantaged kindergarteners. *Psychology, Health & Medicine, 21*(7), 871–881. https://doi.org/10.1080/13548506.2015.1125007

Gu, X., Keller, M.J., Weiller-Abels, K.H., & Zhang, T. (2018). The roles of physical activity and sedentary behavior on Hispanic children's mental health: A motor skill perspective. *Quality of Life Research, 27*(1), 185–193. https://doi.org/10.1007/s11136-017-1687-1

Guthold, R., Stevens, G.A., Riley, L.M., & Bull, F.C. (2020). Global trends in insufficient physical activity among adolescents: A pooled analysis of 298 population-based surveys with 1·6 million participants. *The Lancet Child & Adolescent Health, 4*(1), 23–35. https://doi.org/10.1016/S2352-4642(19)30323-2

Hogan, J.W., Roy, J., & Korkontzelou, C. (2004). Handling drop-out in longitudinal studies. *Statistics in Medicine, 23*(9), 1455–1497. https://doi.org/10.1002/sim.1728

Hox, J.J., Moerbeek, M., & van de Schoot, R. (2010). *Multilevel analysis: Techniques and applications* (2nd ed.). Taylor & Francis Group. http://ebookcentral.proquest.com/lib/jyvaskyla-ebooks/detail.action?docID=574571

Hulteen, R.M., Morgan, P.J., Barnett, L.M., Stodden, D.F., & Lubans, D.R. (2018). Development of foundational movement skills: A conceptual model for physical activity across the lifespan. *Sports Medicine, 48*(7), 1533–1540. https://doi.org/10.1007/s40279-018-0892-6

Jago, R., Salway, R., Emm-Collison, L., Sebire, S.J., Thompson, J.L., & Lawlor, D.A. (2020). Association of BMI category with change in children's physical activity between ages 6 and 11 years: A longitudinal study. *International Journal of Obesity, 44*(1), 104–113. https://doi.org/10.1038/s41366-019-0459-0

Jones, D., Innerd, A., Giles, E.L., & Azevedo, L.B. (2020). Association between fundamental motor skills and physical activity in the early years: A systematic review and meta-analysis. *Journal of Sport and Health Science, 9*(6), 542–552. https://doi.org/10.1016/j.jshs.2020.03.001

Kristman, V., Manno, M., & Côté, P. (2004). Loss to follow-up in cohort studies: How much is too much? *European Journal of Epidemiology, 19*(8), 751–760. https://doi.org/10.1023/b:ejep.0000036568.02655.f8

Laukkanen, A., Niemistö, D., Finni Juutinen, T., Cantell, M., Korhonen, E., & Sääkslahti, A. (2018). Correlates of physical activity parenting: The skilled kids study. *Scandinavian Journal of Medicine and Science in Sports, 28*(12), 2691–2701. https://doi.org/10.1111/sms.13287

Li, L., & Moosbrugger, M.E. (2021). Correlations between physical activity participation and the environment in children and adolescents: A systematic review and meta-analysis using ecological frameworks. *International Journal of Environmental*

Research and Public Health, 18(17), Article 9080. https://doi.org/10.3390/ijerph18179080

Lima, R.A., Pfeiffer, K., Larsen, L.R., Bugge, A., Moller, N.C., Anderson, L.B., & Stodden, D.F. (2017). Physical activity and motor competence present a positive reciprocal longitudinal relationship across childhood and early adolescence. *Journal of Physical Activity & Health, 14*(6), 440–447. https://doi.org/10.1123/jpah.2016-0473

Lopes, V.P., Malina, R.M., Lopes, L.R.S., Stodden, D.F., & Rodrigues, L.P. (2021). Testing the motor proficiency barrier hypothesis for physical activity and weight status in youth. *Journal of Sport & Health Research, 13*(1), 103–116.

Lounassalo, I., Salin, K., Kankaanpää, A., Hirvensalo, M., Palomäki, S., Tolvanen, A., Yang, X., & Tammelin, T.H. (2019). Distinct trajectories of physical activity and related factors during the life course in the general population: A systematic review. *BMC Public Health, 19*(1), Article 271. https://doi.org/10.1186/s12889-019-6513-y

Martin, L., Kokko, S., Villberg, J., Suomi, K. & Alg, K. (2023). Itsearvioitu liikunta-aktiivisuus, liikuntatilanteet, liikkumisympäristöt ja liikkumisen seurantalaitteet. In S. Kokko & L. Martin (Eds.), *Lasten ja nuorten liikuntakäyttäytyminen Suomessa. Liitu-tutkimuksen tuloksia 2022* (pp. 16–29). Valtion liikuntaneuvoston julkaisuja.

Melby, P.S., Elsborg, P., Nielsen, G., Lima, R.A., Bentsen, P., & Andersen, L.P. (2021). Exploring the importance of diversified physical activities in early childhood for later motor competence and physical activity level: A seven-year longitudinal study. *BMC Public Health, 21,* Article 1492. https://doi.org/10.1186/s12889-021-11343-1

Migueles, J.H., Cadenas-Sanchez, C., Ekelund, U., Delisle Nyström, C., Mora-Gonzalez, J., Löf, M., Labayen, I., Ruiz, J.R., & Ortega, F.B. (2017). Accelerometer data collection and processing criteria to assess physical activity and other outcomes: A systematic review and practical considerations. *Sports Medicine, 47*(9), 1821–1845. https://doi.org/10.1007/s40279-017-0716-0

Niemistö, D., Barnett, L.M., Cantell, M., Finni, T., Korhonen, E., & Sääkslahti, A. (2019). Socioecological correlates of perceived motor competence in 5- to 7-year-old Finnish children. *Scandinavian Journal of Medicine & Science in Sports, 29*(5), 753–765. https://doi.org/10.1111/sms.13389

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 & Physical Activity, 17*(1), 1–11. https://doi.org/10.1186/s12966-019-0902-6

Palmer, K.K., Stodden, D.F., Ulrich, D.A., & Robinson, L.E. (2021). Using process- and product-oriented measures to evaluate changes in motor skills across an intervention. *Measurement in Physical Education and Exercise Science, 25,* 273–282. https://doi.org/10.1080/1091367X.2021.1876069

Park, J.H., Moon, J.H., Kim, H.J., Kong, M.H., & Oh, Y.H. (2020). Sedentary lifestyle: Overview of updated evidence of potential health risks. *Korean Journal of Family Medicine, 41*(6), 365–373. https://doi.org/10.4082/kjfm.20.0165

Pate, R.R., Hillman, C.H., Janz, K.F., Katzmarzyk, P.T., Powell, K.E., Torres, A., & Whitt-Glover, M.C. (2019). Physical activity and health in children younger than 6 years: A systematic review. *Medicine & Science in Sports & Exercise, 51*(6), 1282–1291. https://doi.org/10.1249/MSS.0000000000001940

Pate, R.R., O'Neill, J.R., & Mitchell, J. (2010). Measurement of physical activity in preschool children. *Medicine & Science in Sports & Exercise, 42*(3), 508–512. https://doi.org/10.1249/MSS.0b013e3181cea116

Pearson, N., Braithwaite, R.E., Biddle, S.J.H., van Sluijs, E.M.F., & Atkin, A.J. (2014). Associations between sedentary behaviour and physical activity in children and adolescents: A meta-analysis. *Obesity Reviews, 15*(8), 666–675. https://doi.org/10.1111/obr.12188

Penpraze, V., Reilly, J.J., MacLean, C.M., Montgomery, C., Kelly, L.A., Paton, J.Y., Aitchison, T., & Grant, S. (2006). Monitoring of physical activity in young children: How much is enough? *Pediatric Exercise Science, 18*(4), 483–491. https://doi.org/10.1123/pes.18.4.483

Prince, S.A., Roberts, K.C., Melvin, A., Butler, G.P., & Thompson, W. (2020). Gender and education differences in sedentary behaviour in Canada: An analysis of national cross-sectional surveys. *BMC Public Health, 20*(1), Article 1170. https://doi.org/10.1186/s12889-020-09234-y

Rainham, D.G., Bates, C.J., Blanchard, C.M., Dummer, T.J., Kirk, S.F., & Shearer, C.L. (2012). Spatial classification of youth physical activity patterns. *American Journal of Preventive Medicine, 42*(5), e87–e96. https://doi.org/10.1016/j.amepre.2012.02.011

Rey, E., Carballo-Fazanes, A., Varela-Casal, C., & Abelairas-Gómez, C. (2020). Reliability of the test of gross motor development: A systematic review. *PLoS One, 15*(7), Article e0236070. https://doi.org/10.1371/journal.pone.0236070

Reyes, A.C., Chaves, R., Baxter-Jones, A.D.G., Vasconcelos, O., Barnett, L.M., Tani, G., Hedeker, D., & Maia, J. (2019). Modelling the dynamics of children's gross motor coordination. *Journal of Sports Sciences, 37*(19), 2243–2252. https://doi.org/10.1080/02640414.2019.1626570

Ricardo, L., Wendt, A., dos Santos Costa, C., Mielke, G.I., Brazo-Sayavera, J., Khan, A., Kolbe-Alexander, T.L., & Crochemore-Silva, I. (2022). Gender inequalities in physical activity among adolescents from 64 Global South countries. *Journal of Sport and Health Science, 11*(4), 509–520. https://doi.org/10.1016/j.jshs.2022.01.007

Robinson, L.E., Stodden, D.F., Barnett, L.M., Lopes, V.P., Logan, S.W., Rodrigues, L.P., & D'Hondt, E. (2015). Motor competence and its effect on positive developmental trajectories of health. *Sports Medicine, 45*(9), 1273–1284. https://doi.org/10.1007/s40279-015-0351-6

Ross, R.K., Breskin, A., & Westreich, D. (2020). When is a complete-case approach to missing data valid? The importance of effect-measure modification. *American Journal of Epidemiology, 189*(12), 1583–1589. https://doi.org/10.1093/aje/kwaa124

Rubín, L., Gába, A., Pelclová, J., Štefelová, N., Jakubec, L., Dygrýn, J., & Hron, K. (2022). Changes in sedentary behavior patterns during the transition from childhood to adolescence and their association with adiposity: A prospective study based on compositional data analysis. *Archives of Public Health, 80*(1), 1–9. https://doi.org/10.1186/s13690-021-00755-5

Saari, A., Sankilampi, U., Hannila, M.-L., Kiviniemi, V., Kesseli, K., & Dunkel, L. (2011). New Finnish growth references for children and adolescents aged 0 to 20 years: Length/height-for-age, weight-for-length/height, and body mass index-for-age. *Annals of Medicine, 43*(3), 235–248. https://doi.org/10.3109/07853890.2010.515603

Schmutz, E.A., Haile, S.R., Leeger-Aschmann, C.S., Kakebeeke, T.H., Zysset, A.E., Messerli-Bürgy, N., Stülb, K., Arhab, A., Meyer, A.H., Munsch, S., Puder, J.J., Jenni, O.G., & Kriemler, S. (2018). Physical activity and sedentary behavior in preschoolers: A longitudinal assessment of trajectories and determinants. *The International Journal of Behavioral Nutrition and Physical Activity, 15*(1), Article 35. https://doi.org/10.1186/s12966-018-0670-8

Schmutz, E.A., Leeger-Aschmann, C.S., Kakebeeke, T.H., Zysset, A.E., Messerli-Burgy, N., Stulb, K., Arhab, A., Meyer, A.H., Munsch, S., Puder, J.J., Jenni, O.G., & Kriemler, S. (2020). Motor competence and physical activity in early childhood: Stability and relationship. *Frontiers in Public Health, 8,* Article 39. https://doi.org/10.3389/fpubh.2020.00039

Seefeldt, V. (1980). Developmental motor patterns: Implications for elementary school physical education. In C. Nadeau, W. Holliwell, & G. Roberts (Eds.), *Psychology of motor behavior and sport* (pp. 314–323). Human Kinetics.

Stodden, D.F., Goodway, J., Langendorfer, S.J., Roberton, M.A., Rudisill, M.E., Garcia, C., & Garcia, L.E. (2008). A developmental perspective on the role of motor skill competence in physical activity: An emergent relationship. *Quest, 60,* 290–306. https://doi.org/10.1080/00336297.2008.10483582

Tucker, P. (2008). The physical activity levels of preschool-aged children: A systematic review. *Early Childhood Research Quarterly, 23*(4), 547–558. https://doi.org/10.1016/j.ecresq.2008.08.005

Turunen, M., Kulmala, J., Hakonen, H. & Tammelin, T. (2023). Aktiivisesti kuljetut koulumatkat. In S. Kokko & L. Martin (Eds.), *Lasten ja nuorten liikuntakäyttäytyminen Suomessa*. *Liitu-tutkimuksen tuloksia 2022* (pp. 78–81). Valtion liikuntaneuvoston julkaisuja.

Ulrich, D.A. (2013). The Test of Gross Motor Development-3 (TGMD-3): Administration, scoring, & international norms. *Spor Bilimleri Dergisi, 24*(2), 27–33.

Ulrich, D.A. (2019). *Test of gross motor development: Examiner's manual* (3rd ed.). Pro-Ed.

UNICEF. (2022). *Early childhood development overview*. https://data.unicef.org/topic/early-childhood-development/overview/

Valentini, N.C., Duarte, M.G., Zanella, L.W., & Nobre, G.C. (2022). Test of Gross Motor Development-3: Item difficulty and item differential functioning by gender and age with Rasch analysis. *International Journal of Environmental Research and Public Health, 19*(14), Article 8667. https://doi.org/10.3390/ijerph19148667

World Health Organization. (2019). *Guidelines on physical activity, sedentary behaviour and sleep for children under 5 years of age*. https://apps.who.int/iris/handle/10665/311664

World Health Organization. (2020). *WHO guidelines on physical activity and sedentary behaviour*. https://www.who.int/publications-detail-redirect/9789240015128

Xin, F., Chen, S.-T., Clark, C., Hong, J.-T., Liu, Y., & Cai, Y.-J. (2020). Relationship between fundamental movement skills and physical activity in preschool-aged children: A systematic review. *International Journal of Environmental Research and Public Health, 17*(10), Article E3566. https://doi.org/10.3390/ijerph17103566

Zheng, Y., Ye, W., Korivi, M., Liu, Y., & Hong, F. (2022). Gender differences in fundamental motor skills proficiency in children aged 3–6 years: A systematic review and meta-analysis. *International Journal of Environmental Research and Public Health, 19*(14), Article 8318. https://doi.org/10.3390/ijerph19148318