Author(s): Kasanen, Maria; Laukkanen, Arto; Niemistö, Donna; Tolvanen, Asko; Ortega, Francisco; Sääkslahti, Arja

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Bidirectional Relationship Over Time Between Body Mass Index and Fundamental Movement Skill Domains Measured by a Process-Oriented Method in Childhood: A 3-Year Longitudinal Study

Maria Kasanen, Arto Laukkanen, Donna Niemistö, Asko Tolvanen, Francisco Ortega, and Arja Sääkslahti
Faculty of Sport and Health Sciences, University of Jyväskylä, Jyväskylä, Finland

The worldwide increase in childhood overweight and obesity underscores the need to study variables like fundamental movement skill (FMS) levels from early childhood. This study investigated the bidirectional longitudinal relationship between body mass index (BMI) and process-oriented FMSs, including locomotor skills and object control skills in 675 Finnish children, aged 3–8 years at baseline (50.5% female, mean age 5.5 years) over 3 years. Standardized BMI-for-age *SD* scores (BMI SDS *z*-scores) followed Finnish national standards. The FMS assessment comprised four subtests from the Test of Gross Motor Development, third edition. Age-adjusted standardized residuals of FMS or skill domains and BMI SDS *z*-scores were used in a two-level, cross-classified, cross-lagged regression analysis, accounting for gender, and baseline value of the dependent variables. The results showed no statistically significant longitudinal relationship between BMI and FMS or its skill domains for either gender in either direction. This suggests that BMI and process-oriented FMS, encompassing locomotor skill and object control skill, develop independently, possibly influenced by unexplored variables. These findings contradict earlier results based on product-oriented measurements, which may include a physical capacity component. The

Laukkanen https://orcid.org/0000-0002-9722-0258
Niemistö https://orcid.org/0000-0002-9198-9437
Tolvanen https://orcid.org/0000-0001-6430-8897
Ortega https://orcid.org/0000-0003-2001-1121
Sääkslahti https://orcid.org/0000-0003-4354-0990
Kasanen (maria.kasanen@gmail.com) is corresponding author, https://orcid.org/0000-0003-0057-3610

outcomes further underscore the importance of monitoring weight status from early childhood, given its significant association with later-life weight conditions.

Keywords: children, early childhood, motor development

Childhood overweight and obesity have emerged as significant global issues due to their high prevalence (NCD Risk Factor Collaboration, 2017). The World Health Organization (2021) characterizes overweight and obesity as "abnormal or excessive fat accumulation that may impair health." The body mass index (BMI) serves as a practical method for identifying children who are overweight and obese, although the BMI does not directly measure body fat levels (Martin-Calvo et al., 2016).

Evidence shows a strong longitudinal relationship between obesity in childhood and adulthood, starting in early childhood (Rooney et al., 2011) with children aged 8 years or younger (UNICEF, 2022). Thus, understanding the factors underlying overweight and obesity in childhood is important. Fundamental movement skills (FMSs), which represent the performance level of foundational mechanisms (neural, muscular, biomechanical, and perceptual) that drive gross motor movements (Goodway et al., 2019), are considered to share an inverse bidirectional relationship with overweight and obesity during childhood (Robinson et al., 2015). Hence, improved FMSs may help prevent the conditions of obesity and being overweight through physical activity, while a higher weight status might be associated with poorer FMSs, especially for tasks requiring manipulation of total body mass (Robinson et al., 2015). A systematic review (Barnett et al., 2021) supports this inverse bidirectional relationship between weight status and FMS level in childhood.

Evidence suggests that BMI may differentially affect the multiple FMS domains, such as locomotor skills (LMSs) and object control skills (OCSs; Barnett et al., 2016). A higher BMI can impact LMSs due to movement against gravity, while the relationship between BMI and OCSs, which are more static, remains unclear (Okely et al., 2004). According to the same systematic review, higher BMI or body fat levels negatively affect LMSs, but a reverse pathway from LMS level to weight status and relationships between OCS level and weight status is indeterminate because longitudinal research is limited (Barnett et al., 2021). Therefore, more longitudinal studies focusing on these skill domains are needed.

FMS can be measured using different metrics and approaches (Hulteen et al., 2020) such as process- or product-oriented metrics. Process-oriented tests assess the quality of movement through specific performance criteria, focusing on patterns and techniques, whereas product-oriented tests measure outcomes such as speed, distance, height, or the number of repetitions without considering the method of execution (Williams & Monsma, 2006). These measures correlate to some extent, ranging from low to moderate (Ré et al., 2018), and evaluate different aspects of FMS (Palmer et al., 2021; Ré et al., 2018).

To our knowledge, ours is the first study to investigate the bidirectional longitudinal relationship that BMI has with FMS level or, separately, with LMS and OCS levels, measured via a process-oriented approach from early childhood. Previous studies (D'Hondt et al., 2014; Lima et al., 2019) have investigated the bidirectional longitudinal relationship between FMSs, measured via the product-oriented Körperkoordinationstest für Kinder assessment, and BMI (D'Hondt et al., 2014) or body fatness (Lima et al., 2019) from early childhood. Both studies (D'Hondt et al., 2014; Lima et al., 2019) reported significant inverse bidirectional longitudinal relationships between FMS and both BMI and body fatness, respectively.

However, it is crucial to report research findings on the bidirectional longitudinal relationship of FMS and BMI using process-oriented measures as well because this approach may potentially offer a more accurate picture of the longitudinal relationship between FMS and BMI. Few studies have examined the longitudinal relationship from process-oriented FMSs or skill domains to weight status (Duncan et al., 2021; Foulkes et al., 2021; Vlahov et al., 2014) or the reverse (Lopes et al., 2020) starting in early childhood, and the findings of those studies have been inconsistent. The process-oriented Test of Gross Motor Development, second edition (TGMD-2), was used in these studies. While Duncan et al. (2021) and Vlahov et al. (2014) identified inverse relationships between FMS and BMI or body fatness, Foulkes et al. (2021) and Lopes et al. (2020) found no significant relationship between FMS, LMS, or OCS and an individual's likelihood of becoming overweight or obese.

The partially contradictory findings and limited prior research highlight the need for additional research into the bidirectional longitudinal relationship between weight status and both FMS levels and skill levels in the composite domains separately, particularly from the perspective of process-oriented methods of measuring FMS. The present study examined this relationship using standardized BMI-for-age SD scores (BMI SDS *z*-scores) and process-oriented age-residualized FMS levels starting from early childhood in Finnish children aged 3–8 years at baseline over a 3-year follow-up period. Additionally, the study considered the relationships between BMI SDS *z*-scores and age-residualized skill domains—that is, LMS and OCS—as distinct relationships that may exist (Barnett et al., 2016; Okely et al., 2004). Drawing on existing theory (Robinson et al., 2015) and previous systematic reviews (Barnett et al., 2021), we hypothesize a bidirectional relationship between BMI and FMSs over time. Specifically, we expect that higher baseline BMI levels will predict lower FMSs at follow-up, while proficient baseline FMSs will predict lower subsequent BMI levels. This bidirectional influence suggests that elevated BMI in early childhood may impact development of FMSs negatively in later childhood and, conversely, that proficient FMSs in early childhood may be associated with a reduction in BMI 3 years later. In particular, we anticipate a negative bidirectional relationship between BMI and LMS, as the literature has indicated (Barnett et al., 2016; D'Hondt et al., 2014; Lima et al., 2019; Okely et al., 2004). Given that FMS development exhibits gender differences (Barnett et al., 2016) and that BMI may also be influenced by gender (Shah et al., 2020), our analysis specifically investigated gender differences by examining the interactions between gender and FMS or skill domains, and between gender and BMI.

Materials and Methods

The longitudinal data used in this study were collected at two measurement points from 950 Finnish children who participated in the geographical cluster-randomized Skilled Kids study (2015–2016) and for whom comprehensive data were available on the main study variables (parental support for child physical activity and outdoor time) of the follow-up research, referred to as the Active Family study (2018–2020). Of these 950 children, 675 participated in the measurements approximately 3 years later (mean = 3.23 years, range = 2.39–4.55 years), and these 675 ultimately were included in the study. From a bias perspective, the rate of loss to follow-up (29%) was considered acceptable (Kristman et al., 2004), and the missing data were found to be missing completely at random (Little's MCAR test chi-square = 118.773, degrees of freedom = 141, $p = .913$), considering all model-involved variables. Participants were nested within 36 childcare centers and 97 schools.

Before data collection was initiated, participants' parents provided written informed consent for their own and their children's voluntary participation in the study and for data merging. The Ethics Committee of the University of Jyväskylä granted ethical approval for the baseline on October 30, 2015, and for the follow-up on June 28, 2018.

Measurements

Gender, Age, and BMI

Parents provided their children's gender (options: girl or boy) and birth date in the baseline questionnaire. The exact ages of the children at both the baseline and follow-up points were calculated by comparing the birth date to the date of the assessment.

Body mass (seca 877, seca GmbH and Co. KG) and height (HM 200P, Charder Electronic Co., Ltd.) were measured directly to the nearest decimal, with children lightly dressed and barefoot. BMI SDSs and BMI categories were calculated based on Finnish national standards (Saari et al., 2011). The BMI SDS values were subsequently converted to *z*-scores (BMI SDS *z*-scores) that were standardized separately for boys and girls, reflecting gender-specific differences in interpreting the scores. For comparison in the descriptive statistics, International Obesity Task Force BMI categories (Cole & Lobstein, 2012) were assigned using a classifier (Sanchez-Delgado et al., n.d.).

FMSs and Skill Domains

The FMS score (maximum 28 points) was derived from the sum of the following four subtests from the process-oriented TGMD-3: two LMS subtests (skip, 0–6 points, and one-legged hop, 0–8 points; maximum 14 points) and two OCS subtests (overhand throw, 0–8 points, and one-handed stationary dribble, 0–6 points; maximum 14 points; Ulrich, 2019). These subtests were selected from those that best represented the skill domains (Wagner et al., 2016). Each subtest was performed twice and qualitatively evaluated by a trained observer using specific performance criteria (Ulrich, 2019).

The TGMD-3 is designed for children aged 3–11 years old (Ulrich, 2019). Both the inter- and intrarater reliability of the TGMD-3 were >0.9, and the test–retest reliability exceeded 0.8. Moreover, the internal consistency of the TGMD-3 ranged from acceptable to excellent (Cronbach's alpha .7–.9; Rey et al., 2020). The intraclass correlation coefficients (ICCs = .730–.757) for consistency between different research teams were viewed as fair for the FMS scores, LMS scores, and OCS scores measured using the TGMD-3. However, the agreement ICCs

(.363–.478) were viewed as poor. Therefore, this variability suggests that comparisons between studies or research groups employing the TGMD-3 may not always be reliable (Hulteen et al., 2023). In this study, the same research group performed the TGMD-3 measurements at baseline and at follow-up.

As FMSs are related to age (Barnett et al., 2016), age-adjusted FMS, LMS, and OCS standardized residuals (FMSzre, LMSzre, and OCSzre, respectively) were employed to address the strong correlation between the scores and age (baseline: .460–.602; follow-up: .309–.397; Wurm & Fisicaro, 2014) and to eliminate the influence of varying durations between measurements and different ages (Duncan et al., 2021) at baseline and follow-up. Standardized residuals at baseline were used as predictors, while residuals at follow-up were used as dependent variables. This adjustment allowed for an interpretation of how participants deviated from average FMS, LMS, or OCS scores for their age, with positive residuals indicating performance above the age-predicted value and negative residuals indicating performance below the expected level.

Data Analyses

We employed two-level, cross-classified models (Finch & Bolin, 2017) to analyze the data due to the clustered nature of the data, as participants (Level 1) were cross-classified (Level 2) by 36 childcare centers (on average, 18.1 participants, range 5–35) and 97 schools (on average, 6.9 participants, range 1–31). Only predictors at the individual level (Level 1) were measured and incorporated into the analyses.

Cross-lagged models (Kearney, 2017) were used in the two-level, cross-classified analysis to investigate the bidirectional relationship between BMI SDS *z*-scores and FMSzre. The following models were implemented: (a) an intercept-only model for outcomes (FMSzre and BMI SDS *z*-scores at follow-up) with no predictors to verify the appropriateness of multilevel analysis; (b) a model that included individual-level predictors (FMSzre and BMI SDS *z*-scores at baseline) along with interactions of FMSzre × Gender and BMI SDS *z*-scores × Gender at baseline; and (c) separate models for girls and boys with individual-level predictors (FMSzre and BMI SDS *z*-scores at baseline), executed if the interaction between the baseline FMSzre and gender, or between baseline BMI SDS *z*-scores and gender was a statistically significant predictor in the previous model. To account for the multilevel structure of the data, all variables were allowed to correlate at the between levels. The same models were executed with two skill domains, LMSzre and OCSzre, individually serving as predictors and outcome variables instead of using FMSzre. All predictors were grand mean centered (Finch & Bolin, 2017) in the analyses.

The models were implemented using a Bayesian analysis with algorithms of an iterative Markov chain Monte Carlo method (using the algorithm: GIBBS[PX1], point estimate—median, two parallel Markov chain Monte Carlo chains, maximum 50,000 iterations). Bayesian approaches utilize a distribution of values. Prior distributions (mean 0, variance ∞) were selected with the aim of obtaining parameter estimates based on the observed data. Convergence of the posterior distribution was confirmed by potential scale reduction coefficients (below 1.05) and trace plots. Autocorrelation plots were employed to examine an acceptable level of autocorrelation (Finch & Bolin, 2017).

The standardization of BMI SDS and the residualization of FMS, LMS, and OCS, along with the descriptive statistical analysis, were performed using SPSS (version 28, IBM) software. Two-level cross-classified, cross-lagged models, and correlations between variables within models, were conducted using Mplus (version 8.8, Muthén & Muthén). The statistical significance level was set at a probability of <.05 for all analyses. Credibility intervals (C.I.) for the Bayesian cross-classified models were interpreted similarly to confidence intervals (CI) in frequentist models (Finch & Bolin, 2017).

The model fit was evaluated using the posterior predictive probability value (PPP) and the 95% CI for the difference between observed and replicated chi-square values. The PPP values near .5 suggested an optimal model fit, and a 95% CI that included zero indicated a fitting model (Finch & Bolin, 2017).

Results

Descriptive Statistics

Descriptive statistics at baseline and follow-up are displayed in Table 1. Statistically significant differences between girls and boys were observed in LMS and OCS at both baseline and follow-up ($p < .001$). Gender differences in FMS were statistically significant only at follow-up ($p = .002$). The baseline data included measurements from two girls ages 2.97 years. This age is marginally below the validated age threshold of 3 years for the TGMD-3.

For comparison, the distribution of the participants' weight statuses according to Finnish BMI-for-age references with five categories (Saari et al., 2011) and International Obesity Task Force references with eight categories (Cole & Lobstein, 2012; Sanchez-Delgado et al., n.d.), classified as underweight, normal weight, overweight, obesity, and total overweight and obesity, is presented in the Supplementary Table S1 (available online). The distributions of the participants' weight statuses, particularly the proportions of girls and boys, appear to differ between the Finnish and International Obesity Task Force references, as noted in previous research (Saari et al., 2011). However, the proportion of overweight and obese girls (18.0%–18.6%) and boys (27.1%–29.7%) in this study aligns closely with the proportion of overweight and obese Finnish children of the same age (girls: 16.0%–19.0%, boys: 27.0%–30.0%) that was reported in Finnish references (Jääskeläinen et al., 2021).

Table 2 indicated to a strong correlation between baseline and follow-up BMI SDS *z*-scores ($r = .774–.775$, $p < .001$) but showed no relationship between BMI SDS *z*-scores and FMSzre, or between BMI SDS *z*-scores and age-residualized skill domains. Likewise, within-variable correlations between baseline and follow-up were statistically significant for FMSzre, LMSzre, and OCSzre ($r = .281–.390$, $p \leq .001$).

The results of the intercept-only model indicated that FMSzre, LMSzre, and OCSzre and the BMI SDS *z*-scores exhibited statistically significant variations (Table 3) across childcare centers (1.9%–6.0%, $p < .001$) and schools (1.0%–5.2%, $p < .001$). The statistical significance of the between-level variances suggests that multilevel analytical techniques were warranted.

Table 1 Descriptive Statistics for Age, TGMD-3-Based FMSs (Maximum: 28 Points), LMSs (Maximum: 14 Points), OCSs (Maximum: 14 Points), and Finnish National Standards-Based BMI *SD* Scores at Baseline and Follow-Up ($N = 675$)

	N	*M*	*SD*	Minimum	Maximum	Gender differences (*p*)
Age at baseline	675	5.53	1.09	2.97[a]	7.80	.303
Girls	341	5.48	1.10	2.97	7.29	
Boys	334	5.58	1.08	3.10	7.80	
Age at follow-up	674	8.76	1.08	6.33	11.44	.316
Girls	341	8.72	1.08	6.72	11.44	
Boys	333	8.80	1.09	6.33	11.28	
FMS at baseline	596	12.2	5.4	0	27	.439
Girls	299	12.3	4.9	0	24	
Boys	297	12.0	5.8	0	27	
FMS at follow-up	643	17.2	5.0	0	28	**.002**
Girls	328	16.7	4.3	5	27	
Boys	315	17.8	5.5	0	28	
LMS at baseline	602	7.0	3.5	0	14	**<.001**
Girls	304	7.7	3.3	0	14	
Boys	298	6.4	3.5	0	14	
LMS at follow-up	645	8.9	2.9	0	14	**<.001**
Girls	330	9.5	2.5	2	14	
Boys	315	8.3	3.2	0	14	
OCS at baseline	604	5.1	3.1	0	14	**<.001**
Girls	302	4.6	2.6	0	12	
Boys	302	5.7	3.3	0	14	
OCS at follow-up	648	8.3	3.3	0	14	**<.001**
Girls	329	7.2	2.8	0	14	
Boys	319	9.4	3.3	0	14	
BMI SDS at baseline	621	0.18	1.05	–4.55	3.24	.325
Girls	311	0.21	1.13	–4.55	3.24	
Boys	310	0.14	0.95	–3.37	2.47	
BMI SDS at follow-up	641	0.22	0.99	–3.43	3.22	.580
Girls	328	0.25	1.02	–3.01	3.22	
Boys	313	0.19	0.96	–3.43	2.51	

Note. *p* values of gender differences under .05 are shown in bold. LMS = locomotor skill level; OCS = object control skill level; FMS = fundamental movement skill level; BMI SDS = body mass index *SD* score; TGMD-3 = Test of Gross Motor Development, third edition.

[a]The baseline data include measurements from two girls ages 2.97 years.

Table 2 Correlations Within Models: Standardized BMI SDS Scores and Age-Residualized FMSs and Skill Domain Levels at Baseline and Follow-Up

	BMI SDS *z*-scores		FMSzre	
	Baseline	Follow-up	Baseline	Follow-up
BMI SDS *z*-scores at baseline	1			
BMI SDS *z*-scores at follow-up	0.774[a]	1		
FMSzre at baseline	–0.032	–0.035	1	
FMSzre at follow-up	0.002	0.002	0.390[a]	1

	BMI SDS *z*-scores		LMSzre		OCSzre	
	Baseline	Follow-up	Baseline	Follow-up	Baseline	Follow-up
BMI SDS *z*-scores at baseline	1					
BMI SDS *z*-scores at follow-up	0.775[a]	1				
LMSzre at baseline	–0.061	–0.058	1			
LMSzre at follow-up	–0.028	–0.036	0.299[a]	1		
OCSzre at baseline	0.019	0.010	0.113[a]	0.219[a]	1	
OCSzre at follow-up	0.032	0.035	0.099[a]	0.189[a]	0.281[a]	1

Note. BMI SDS = body mass index *SD* score; FMSzre = age-residualized fundamental movement skill level; LMSzre = age-residualized locomotor skill level; OCSzre = age-residualized object control skill level.
[a]Correlation is significant at the .05 level (two-tailed).

Bidirectional Longitudinal Relationship Between Standardized BMI-for-Age *SD* Score and Age-Residualized FMSs

Table 4 displays the outcomes of individual-level predictors in the bidirectional relationship between BMI SDS *z*-scores and FMSzre. An interaction between baseline FMSzre and gender significantly predicted both BMI SDS *z*-scores ($\beta = -0.076$, $p = .006$) and FMSzre ($\beta = 0.142$, $p < .001$) at follow-up. However, the final models (Table 5) revealed no statistically significant bidirectional longitudinal relationship between BMI SDS *z*-scores and FMSzre for either

Table 3 Variation in Standardized BMI SDS Score, and Age-Residualized FMS, LMS, and OCS Levels Across Childcare Centers and Schools According to Intercept-Only Models

	Intercept-only models (*N* = 649, 36 childcare centers and 94 schools)				
Variance	BMI SDS *z*-scores	FMSzre	BMI SDS *z*-score	LMSzre	OCSzre
$\sigma_{childcarecenter}$ (ICC)	0.019* (.019)	0.061* (.060)	0.021* (.021)	0.041* (.040)	0.026* (.026)
σ_{school} (ICC)	0.019* (.019)	0.023* (.023)	0.027* (.027)	0.009* (.009)	0.053* (.052)

Note. BMI SDS = body mass index *SD* score; FMSzre = age-residualized fundamental movement skill level; LMSzre = age-residualized locomotor skill level; OCSzre = age-residualized object control skill level; ICC = intraclass correlation coefficient.
*Significant at $p < .05$.

Table 4 Results of the Analysis of the Bidirectional Longitudinal Relationship Between Standardized BMI SDS Scores and Age-Residualized FMS Level, Including Gender and Interactions as Predictors

	Outcomes at follow-up (*N* = 673, 36 childcare centers and 97 schools)	
Individual-level predictors at baseline	BMI SDS *z*-scores (95% C.I.)	FMSzre (95% C.I.)
BMI SDS *z*-cores	0.774* [0.739, 0.805]	0.011 [–0.065 to 0.087]
FMSzre	–0.005 [–0.059 to 0.050]	0.379* [0.303, 0.449]
Gender	–0.005 [–0.058 to 0.047]	0.153* [0.080, 0.225]
FMSzre × Gender	–0.076* [–0.130 to – 0.022]	0.142* [0.064, 0.218]
BMI SDS *z*-scores × Gender	0.006 [–0.048 to 0.058]	0.057 [–0.021 to 0.133]
Within-level R^2	.606* [.553, .655]	.206* [.146, .269]

Note. C.I. = credibility interval; BMI SDS = body mass index *SD* score; FMSzre = age-residualized fundamental movement skill level.
*Significant at $p < .05$.

Table 5 Results of the Analysis of the Bidirectional Longitudinal Relationship Between the Standardized BMI SDS Score and Age-Residualized FMS Levels in Girls and Boys

Individual-level predictors at baseline	Outcomes at follow-up			
	Girls (n = 340, 36 childcare centers and 76 schools)		Boys (n = 332, 36 childcare centers and 76 schools)	
	BMI SDS *z*-scores (95% C.I.)	FMSzre (95% C.I.)	BMI SDS *z*-scores (95% C.I.)	FMSzre (95% C.I.)
BMI SDS *z*-scores	0.757* [0.700, 0.805]	–0.056 [–0.175, 0.066]	0.780* [0.727, 0.824]	0.037 [–0.066, 0.140]
FMSzre	0.063 [–0.018, 0.145]	0.262* [0.142, 0.376]	–0.079 [–0.158, 0.001]	0.516* [0.417, 0.603]
Within-level R^2	.573* [.492, .647]	.077* [.026, .152]	.614* [.536, .683]	.271* [.179, .369]

Note. C.I. = credibility interval; BMI SDS = body mass index *SD* score; FMSzre = age-residualized fundamental movement skill level.
*Significant at $p < .05$.

gender. Instead, baseline BMI SDS *z*-scores and FMSzre significantly predicted their follow-up values. The model accounted for 57.3%–61.4% of BMI SDS *z*-scores variance and 7.7%–27.1% of FMSzre variance.

Final models for girls and boys were fitted to the data according to the PPP-value (girls: 0.345, boys: 0.340) and a 95% CI for the difference between the observed and the replicated chi-square values (girls: [–20.490, 34.403], boys: [–21.652, 35.113]).

Bidirectional Longitudinal Relationship Between Standardized BMI-for-Age *SD* Scores and Age-Residualized Skill Domains

The findings on the bidirectional relationship between BMI SDS *z*-scores and age-residualized skill domains mirrored the findings presented previously related to BMI SDS *z*-scores and FMSzre. The interactions between age-residualized skill domains and gender (Table 6) predicted at least one of the dependent variables ($\beta = -0.079$ to 0.096, $p = .004$–.020), leading to separate analyses for each gender (Table 7). However, no significant relationship was found between BMI SDS

Table 6 Results of the Analysis of the Bidirectional Longitudinal Relationship Between the Standardized BMI SDS Score and Age-Residualized Skill Domains, Including Gender and Interactions as Predictors

	Outcomes at follow-up (*N* = 673, 36 childcare centers and 97 schools)		
Individual-level predictors at baseline	**BMI SDS z-scores (95% C.I.)**	**LMSzre (95% C.I.)**	**OCSzre (95% C.I.)**
BMI SDS *z*-scores	0.771* [0.735, 0.803]	–0.029 [–0.106, 0.046]	0.041 [–0.031, 0.114]
LMSzre	–0.015 [–0.071, 0.043]	0.223* [0.144, 0.301]	0.174* [0.100, 0.253]
OCSzre	0.004 [–0.051, 0.060]	0.205* [0.123, 0.288]	0.165* [0.086, 0.246]
Gender	–0.010 [–0.067, 0.049]	–0.185* [–0.262, –0.106]	0.389* [0.314, 0.462]
LMSzre × Gender	–0.079* [–0.131, –0.025]	0.035 [–0.046, 0.112]	0.049 [–0.025, 0.125]
OCSzre × Gender	–0.015 [–0.072, 0.040]	0.084* [0.003, 0.163]	0.096* [0.016, 0.173]
BMI SDS *z*-score × Gender	0.004 [–0.049, 0.055]	0.060 [–0.018, 0.139]	0.023 [–0.053, 0.096]
Within-level R^2	.608* [.557, .655]	.176* [.122, .236]	.242* [.180, .304]

Note. C.I. = credibility interval; BMI SDS = body mass index *SD* score; LMSzre = age-residualized locomotor skills; OCSzre = age-residualized object control skills.
*Significant at $p < .05$.

Table 7 Results of the Analysis of the Bidirectional Longitudinal Relationship Between the Standardized BMI SDS Score and Two Age-Residualized Skill Domains (LMSs and OCSs) in Girls and Boys

	Outcomes at follow-up					
	Girls ($n = 340$, 36 childcare centers, 76 schools)			Boys ($n = 332$, 36 childcare centers, 76 schools)		
Individual-level predictors at baseline	BMI SDS *z*-scores (95% C.I.)	LMSzre (95% C.I.)	OCSzre (95% C.I.)	BMI SDS *z*-scores (95% C.I.)	LMSzre (95% C.I.)	OCSzre (95% C.I.)
BMI SDS *z*-scores	0.756* [0.700, 0.804]	–0.090 [–0.208, 0.032]	0.002 [–0.116, 0.120]	0.776* [0.722, 0.820]	–0.013 [–0.124, 0.097]	0.060 [–0.049, 0.167]
LMSzre	0.064 [–0.017, 0.145]	0.219* [0.097, 0.336]	0.158* [0.034, 0.273]	–0.079 [–0.160, 0.002]	0.229* [0.113, 0.337]	0.212* [0.096, 0.321]
OCSzre	0.019 [–0.062 to 0.099]	0.121 [–0.002, 0.240]	0.070 [–0.055, 0.189]	–0.018 [–0.098, 0.061]	0.315* [0.201, 0.421]	0.299* [0.186, 0.409]
Within-level R^2	.573* [.493, .646]	.088* [.033, .164]	.040* [.008, .095]	.616* [.537, .683]	.188* [.108, .278]	.173* [.096, .262]

Note. C.I. = credibility interval; BMI SDS = body mass index *SD* score; LMSzre = age-residualized locomotor skills; OCSzre = age-residualized object control skills.
*Significant at $p < .05$.

z-scores and the age-residualized skill domains for either gender. Instead, baseline BMI SDS *z*-scores and LMSzre significantly predicted their follow-up values, while OCSzre at baseline significantly predicted its follow-up only for boys. The model explained 57.3%–61.6% of BMI SDS *z*-scores variability and 4.0%–18.8% for LMSzre and OCSzre.

The final models for girls and boys fitted to the data according to PPP-value (girls: .201, boys: .198) and 95% CI for the difference between the observed and the replicated chi-square values (girls: [–23.945, 58.084], boys: [–22.426, 59.732]).

Discussion

The present study was intended to investigate the bidirectional longitudinal relationship between BMI SDS *z*-scores and FMSzre, also considering two skill domains—LMSzre and OCSzre—separately, measured by a process-oriented assessment in Finnish children over a 3-year follow-up period, starting from early childhood. The final models revealed no statistically significant bidirectional longitudinal relationship between BMI SDS *z*-scores and FMSzre for either girls or boys, in either direction. Investigating the skill domains separately did not change the results. The lack of a statistically significant longitudinal relationship may suggest that BMI and process-oriented FMS, including the skill domains, develop independently of each other in both girls and boys, and may further suggest that other variables influence their development. Another possibility is that the bidirectional longitudinal relationship does not appear yet in early childhood (Barnett et al., 2021; Robinson et al., 2015). Also, the cultural variations (Adeyemi-Walker et al., 2018; Barnett et al., 2021; Cordovil et al., 2022; Jeong et al., 2023; Robinson et al., 2015) and different methods of measuring and interpreting FMS (Hulteen et al., 2020; Palmer et al., 2021) or weight status (Cheng et al., 2016; Saari et al., 2011; Vlahov et al., 2014) may have affected study results.

The findings of this research do not support the hypothesis of an inverse bidirectional relationship between weight status and FMS described by the theoretical framework (Robinson et al., 2015) or reflected in the findings of a published systematic review (Barnett et al., 2021). Contrary to some evidence from the review (Barnett et al., 2021) suggesting a bidirectional longitudinal relationship between skill domains and weight status, the current study did not find such an association. Furthermore, despite previous research (Okely et al., 2004) suggesting that LMSs might be more influential than OCSs for body movement against gravity, this study did not observe a significant differential impact of LMS and OCS on weight status.

One explanation for the results of this study may be the process-oriented manner in which FMS was measured. The process-oriented test focuses on the quality of movement, including movement patterns and execution methods, through observation of children's body positioning and motion engagement (Williams & Monsma, 2006). In addition, the performance of a process-oriented subtest takes a short time and does not require high levels of physical capacity, whereas product-oriented measures may contain more overlap with the physical capacity component of fitness tests (Utesch et al., 2019), typically involving quantitative information of movement, such as speed, repetitions, height, and length (Williams & Monsma, 2006). For instance, the physical capacity component of FMS has been found to be significant in the relationship between FMS and executive functions (Malambo et al., 2022).

We propose that the physical capacity component of FMS might be the primary reason for the bidirectional longitudinal relationship between BMI and FMS, as measured in a product-oriented manner, which may explain the findings of this study. In addition, prior studies substantiate this conclusion regarding the relationship between the physical capacity element of FMS and BMI or body fatness. Earlier bidirectional longitudinal studies (D'Hondt et al., 2014; Lima et al., 2019) that started in early childhood and employed the product-oriented Körperkoordinationstest für Kinder measure identified an inverse relationship between Körperkoordinationstest für Kinder results and BMI (D'Hondt et al., 2014) or body fatness (Lima et al., 2019).

On the other hand, studies (Duncan et al., 2021; Foulkes et al., 2021; Lopes et al., 2020; Vlahov et al., 2014) that investigated only one direction pathway and used the process-oriented TGMD-2 measure reported partly conflicting results. Foulkes et al. (2021) and Lopes et al. (2020) supported the results of this study, as they found no relationship from FMS, LMS, or OCS to BMI (Foulkes et al., 2021) or a reverse path (Lopes et al., 2020). In contrast, Duncan et al. (2021) showed that baseline LMS subtests, such as jumps and slides, predicted BMI, while Vlahov et al. (2014) found that FMS, LMS, and OCS had a significant relationship to body fatness. However, these studies did not consider baseline BMI (Duncan et al., 2021) or body fatness (Vlahov et al., 2014) as predictive variables, which means that change or development in variables was overlooked, which may have affected the results of the analysis. Nevertheless, the results of this study and of previous studies (Rooney et al., 2011; Simmonds et al., 2016) have demonstrated that baseline BMI is a strong predictor for follow-up BMI.

In addition, previous studies have supported an inverse relationship between weight status and the physical capacity component as measured by physical fitness tests, even in early childhood (Ortega et al., 2013; Silva-Santos et al., 2017). Enhanced physical fitness might increase calorie expenditure, for instance, through an increase in muscle mass (Ortega et al., 2013). The relationship between weight status and physical fitness, or product-oriented FMS, may occur in a similar way, considering the similarities of the tests (Robinson et al., 2015; Utesch et al., 2019). Furthermore, the terminology is often used interchangeably across studies (Utesch et al., 2019). For example, jumping sideways and the standing long jump are considered part of FMS in some studies (D'Hondt et al., 2014; Lima et al., 2019), while in others, the same tests are classified as components of physical fitness (Ruedl et al., 2022). However, notably, conflicting results exist regarding the relationship between BMI and physical fitness (Lopes et al., 2020).

Reliable comparisons of results between studies appear to be challenging due to factors such as different measurement methods and variations in study samples. Weight-measuring methods vary, ranging from body fat assessments (Jeong et al., 2023) to different methods of calculating BMI (Meyers et al., 2013). Additionally, there is a wide range of metrics used by researchers to determine FMS in childhood (Hulteen et al., 2020). Comparing results from different measurement methods is challenging, and even using the same test does not always guarantee reliable comparisons. For example, results from the TGMD-3 can vary between different research teams (Hulteen et al., 2023), and the TGMD-2 and TGMD-3 do not align completely in terms of subtests and scoring, with a particularly notable difference observed in the OCS between the tests (Field et al., 2020). Furthermore, when considering cultural variations and different study populations (e.g., age, sex, ethnicity, and number of overweight or obese children), comparing results becomes even more complex (Adeyemi-Walker et al., 2018; Jeong et al., 2023).

The strength of this research lies in its analysis of longitudinal data gathered from children in their early childhood over an average 3-year period and in its use of a two-level, cross-classified, cross-lagged regression analysis as a statistical method, considering the impacts of childcare centers and schools. We also adopted a process-oriented approach to measure FMS, and we analyzed skill domains separately to explore more precisely the bidirectional longitudinal relationship between BMI and FMS. Furthermore, we used BMI-for-age, which considers age (Saari et al., 2011), and age-residualized FMS, LMS, and OCS, as well as the interaction between FMS, LMS, OCS, and gender, as predictor variables to ensure a more detailed depiction.

Nonetheless, this study did have certain limitations. The first limitation is that FMS levels were based only on the results of four subtests of TGMD-3; thus, LMS and OCS levels were each based on two subtests. This may give a limited picture of skill levels, even though the subtests were selected from among those found to best describe the skill domains (Wagner et al., 2016). Additionally, the potential ceiling effect of TGMD-3 might have influenced the results (Ulrich, 2019). The cultural characteristics and homogeneity of the Finnish sample, especially in terms of BMI, compared with other international studies, could also impact the findings.

More studies are needed in the future that examine the bidirectional longitudinal relationship between FMS and BMI from early childhood to adolescence and beyond. It is also crucial to consider that this relationship may vary between individuals of normal weight and those who are obese (Cheng et al., 2016). Gathering data from the same study population at multiple time points would make the growth curve analysis method also possible. Future research should also aim to compare the bidirectional longitudinal relationship between weight status and FMS, measured using both process- and product-oriented methods. This could enhance our understanding of the relationships between these variables, even though both process- and product-oriented measures of FMS are recommended (Williams & Monsma, 2006).

The results of this study highlight the importance of considering multiple levels of influence when examining the predictors of BMI. They also emphasize that individual differences alone may not fully explain the variation, and variables related to childcare centers and schools should also be considered. A more holistic picture of a bidirectional relationship between BMI and FMS may also require including the influence of the family (Rooney et al., 2011; Scott-Sheldon et al., 2020).

Perspective

The current study suggests that a bidirectional longitudinal relationship between BMI and FMSs or individual skill domains may relate more to the physical capacity component of FMS than the qualitative information gleaned from the process-oriented way of measuring FMS. Thus, we recommend considering the influence of the childcare center, school, and family (Rooney et al., 2011; Scott-Sheldon et al., 2020) in the prevention and treatment of obesity and being overweight, in addition to the individual characteristics of children. Overall, the results of this and a previous study (Rooney et al., 2011) highlight the importance of paying attention to weight status in early childhood because it has a strong association with weight status later in life.

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