Improvements in Motor Competence Skills Are Associated with Improvements in Executive Function and Math Problem-Solving Skills in Early Childhood

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Abstract

Efforts to increase moderate to vigorous physical activity (MVPA) in school-aged children are associated with improved health, cognitive, and academic outcomes. However, questions remain about whether similar benefits are observed in early childhood. We hypothesized that motor competence, not MVPA, would be related to improved cognitive and academic skill development in early childhood. For this study, 283 children were recruited from 13 community-based preschools (55% female; M = 4.2 years old, SD = 0.6; 41% non-Hispanic white, 37% non-Hispanic black; 10% Hispanic, 10% mixed race, 2% Asian, 1% American Indian). Children's physical activity, motor competence, executive function, and math problem-solving skills were measured using the same protocol in three assessments in a single academic year (i.e., fall, winter, and spring). Although motor competence was strongly correlated with contemporaneous measures of executive function and math problem-solving skills (rs = .51–.63), MVPA was weakly correlated with executive function and math problem-solving skills (rs = .03–.18). Mixed linear models demonstrated that improvements in children's motor competence were related to improvements in their executive function and math problem-solving skills (ps < .001); their improvements in MVPA were not statistically significant related to any of the outcomes. These within-child associations provide a stronger basis of inference by controlling for all time-invariant confounders. The results of this study suggest that efforts to improve motor competence skills in young children may improve executive function and math problem-solving skills, though experimental studies are required to rigorously test this idea.

Keywords: motor competence, motor skills, physical activity, MVPA, math problem solving, within-person variability

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Policy directives to increase physical activity are in place for preschool- and school-aged students. For example, the World Health Organization (WHO) recommends that preschool-aged children engage in at least 180 minutes of physical activity per day (60 minutes of which should be moderate to vigorous physical activity [MVPA]), whereas school-aged children are recommended to engage in 60 minutes of MVPA per day (WHO, 2020). Increased levels of physical activity, especially MVPA, are associated with improved health, cognitive, and academic outcomes for school-aged children (Erickson et al., 2019; Institute of Medicine, 2013). Meta-analytic and narrative literature reviews have documented that MVPA is specifically associated with executive function (EF) skills in adults, adolescents, and school-aged children (Barenberg et al., 2011; de Greeff et al., 2018). The benefits of increased MVPA for improved academic outcomes may be due, in part, to the impact of MVPA on improved EF skills (Tomporowski et al., 2015; Tomporowski & Pesce, 2019).

The preponderance of evidence that relates individual differences in MVPA to EF skills and academic outcomes is derived from studies of adults and school-aged children (Singh et al., 2019). Studies involving preschool-aged children consistently demonstrate that they spend most of their time in a sedentary state (Aubert et al., 2018; Chaput et al., 2017; Khalsa et al., 2017; Pate et al., 2015). Studies that have investigated the association between physical activity and cognitive outcomes in preschool-aged samples have varied in the ways that physical activity was operationalized (e.g., reduction in sedentary behavior, acute or habitual impacts of physical activity) and in the range of cognitive outcomes considered (Carson et al., 2016; Tandon et al., 2016). To the best of our knowledge, only three studies have considered the association between habitual MVPA and EF skills in early childhood (Cook et al., 2019; McNeill et al., 2018; Willoughby et al., 2018b). None of these studies documented positive associations between MVPA and EF skills, and two studies reported that higher levels of MVPA were associated with significantly worse performance on EF tasks (Cook et al., 2019; Willoughby et al., 2018b). These latter empirical findings were consistent with speculation that efforts to increase MVPA in early childhood may interfere with EF skill development due to competing demands for energy expenditures that are related to physical activity and brain development (Howard et al., 2016). None of the studies that have investigated the association between habitual MVPA and EF skills in early childhood have utilized research designs or analytic methods that inform within-child inferences, which are most relevant to policy makers and early educators (i.e., the primary interest is not whether the most active children also exhibit better EF skills but rather whether efforts to improve a specific child's physical activity level will result in improvements in her EF skills). We address these issues in this study.

Although public health policy has focused on increasing MVPA among young children, early childhood educators have traditionally emphasized motor skill development (Logan et al., 2012; Riethmuller et al., 2009). Notably, motor skills are malleable during early childhood (Van Capelle et al., 2017), and individual differences in motor competence are associated with EF and academic skill development (Cameron et al., 2016; McClelland & Cameron, 2019; Oberer et al., 2017). Prioritizing motor skill acquisition in early childhood as a general strategy to facilitate early brain and cognitive development represents a counterpoint to the prevailing dogma that narrowly emphasizes the importance of increased physical activity (Myer et al., 2015). Given that motor competence is positively correlated with MVPA in early childhood (Fisher et al., 2005; Williams et al., 2008), it is important that both domains be considered simultaneously as predictors of EF and academic skill development.

In this study, we tested the relative importance of motor competence and MVPA as predictors of EF and math problem-solving skills in a community sample of preschool-aged children. We made novel use of our repeated measures data to test between- and within-child associations, the latter being of primary interest. Based on previous studies of preschool-aged children, we hypothesized that motor competence, not MVPA, would be associated with improved EF and math problem-solving skills.

Method

Participants and Procedures

The Kids Activity and Learning Study was designed to test the associations between children's MVPA and motor competence as they relate to the development of EF and math problem-solving skills. A total of 283 children (3–5 years old) were recruited from 75 classrooms in 13 preschools in the southeastern United States. Invitations were extended to all 3- to 5-year-old children in each preschool. On average, 22 children per preschool participated (*M* = 21.8, *SD* = 10.2, *Range* = 10–45). Participating children were 4.2 years old (*SD* = 0.6) and balanced with respect to sex (55% female). Primary caregiver reports of the children's race and ethnicity were available for 83% of the sample (i.e., *N* = 235; 41% non-Hispanic white, 37% non-Hispanic black; 10% Hispanic, 10% mixed race, 2% Asian, 1% American Indian). Of caregivers, 47% reported obtaining a 4-year degree or higher. Children completed the same data collection activities in each of three, 1-week data collection periods (fall, winter, and spring assessments spanned September to June). Data collection included wearing an accelerometer for the entire week (Monday through Friday at preschool and home, except during nighttime sleep and bathing) and completing cognitive, achievement, and motor assessments (in preschools). The RTI International Institutional Review Board approved all study activities (IRB Study #14239, *Testing the Association between Physical Activity Level and Executive Functions in Early Childhood*).

Measures

Executive Function Touch [EF Touch; Willoughby & Blair (2016)]. EF Touch is a computerized battery of EF tasks that provide performance-based indicators of preschool-aged children's inhibitory control, working memory, and attention-shifting skills. The inhibitory control tasks are modified versions of Simon (Spatial Conflict Arrows), Stroop (Silly Sounds), and Go/No-Go (Animal Go/No-Go) tasks that have been adapted for use with young children. The working memory tasks include a self-ordered pointing task (Pick the Picture) and a working memory span task. The attention-shifting task (Something's the Same) is a flexible item selection task. Each task takes 3–7 minutes to complete. Complete task descriptions appear in the Supplemental Material.

The EF Touch battery has undergone extensive psychometric evaluation (Willoughby et al., 2012; Willoughby et al., 2017). These studies have demonstrated acceptable test-retest reliability for individual tasks (*r*s ≈ .60) and the overall battery score (*r*s > .70) and indicate that individual tasks measure the full range of children's ability (characterized by item response theory information). Following precedent (Camerota et al., 2020; Willoughby et al., 2016), we created three composite scores that reflected each child's average performance across multiple tasks (overall EF, inhibitory control, working memory).

Woodcock-Johnson IV: Applied Problems Subtest [WJ-AP (Schrank et al., 2014a)]. The WJ-AP is a standardized assessment of quantitative abilities consisting of a series of oral math word problems. Evidence of acceptable to excellent test-retest reliability (*r*s = .84–.94) and adequate concurrent validity with the Wechsler Individual Achievement Test – Third Edition (*r*s = .82–.21) was established in a large, nationally representative sample that included preschool-aged children between 2 and 5 years old (Schrank et al., 2014b; Villarreal, 2015).

Bruininks-Oseretsky Test of Motor Proficiency Short Form [BOT-2 (Bruininks & Bruininks, 2005)]. The BOT-2 is a standardized assessment of motor competence, with previous evidence for acceptable test-retest reliability (r = .86) and concurrent validity with the Peabody Developmental Motor Scales – Second Edition (r = .73) (Bruininks & Bruininks, 2005). The BOT-2 items worked well for all children; however, we rely on raw scores because norm-referenced scores were not appropriate for children younger than 4 years of age. The BOT-2 short form measures overall motor skills (it does not support separate consideration of fine and gross motor skills).

ActiGraph wGT3X-BT Accelerometers (Pensacola, FL, USA). Children wore accelerometers on their right hip during waking hours except when bathing for each 5-day data collection period. Accelerometers were initialized to process data in 15-second epochs and calibrated using Pate’s criterion measures for 3- to 5-year-olds using MeterPlus software (version 4.3) to generate proportions of time spent in MVPA. That is, we considered individual differences in the overall proportion of time that children were engaged in MVPA at each of the fall, winter, and spring assessments.

Covariates. Children’s age, sex, and their caregiver’s highest reported level of education were included as demographic covariates. Children’s simple reaction time at each of the three time points was included as a covariate for EF outcomes (Willoughby et al., 2018a).

Analytic Strategy

As summarized in the Supplemental Material (see Tables S1 and S2), 0%–18% of focal study variables had missing data. Multiple imputation was used to create five complete datasets (using PROC MI in version 9.4 of SAS), and all statistical models were fit to all datasets. Parameter estimates combined using Rubin's rules (using SAS PROC MIANALYZE), while variance components were averaged. Mixed linear models were used to test the unique contributions of MVPA and motor competence in the prediction of EF and math problem-solving skills (using SAS PROC MIXED). In separate models, we regressed EF composites and math problem-solving skills on motor competence, MVPA, and covariates. Following Raudenbush (2009), we used a three-level random effect model and applied an adaptive centering approach that replicates a fixed-effects analysis while attending to multiple levels of clustering. The equation is presented as follows, with subscripts i, j, and *t* indexing person, classroom, and time (fall, winter, and spring).

$$Y_{ijt} = \beta_0 + \beta_1\left(MC_{ijt} - \overline{MC}_{ij}\right) + \beta_2\left(MC_{ij} - \overline{MC}_j\right) + \beta_3\left(SRT_{ijt} - \overline{SRT}_{ij}\right) + \beta_4\left(MVPA_{ijt} - \overline{MVPA}_{ij}\right) + \beta_5\left(MVPA_{ij} - \overline{MVPA}_j\right) + \beta_6\left(SRT_{ij} - \overline{SRT}_j\right) + \beta_p\mathbf{X}_{\boldsymbol{ij}} + r_j + u_{ij} + \varepsilon_{ijt},$$

$$\varepsilon_{ijt} \sim (0, \sigma^2),\ u_{ij} \sim (0, \tau_u),\ r_j \sim (0, \tau_r)$$

The adaptive centering approach centered the corresponding predictor on the within-person mean ($i.e.\overline{MC}_{ij}$ or $\overline{MVPA}_{ij}$) or between-person mean ($i.e.\overline{MC}_j\ or\ \overline{MVPA}_j$) and hence decomposed each effect of motor competence and MVPA into two terms: a within-child effect (i.e., β_1 or β_4, the difference between each child's time-varying score and her average score across all completed assessments) and a between-child effect (i.e., β_2 or β_5, the average child score across all completed assessments). The within-child effects were of primary substantive interest because they explicitly tested whether changes in a specific child's motor competence or MVPA were related to corresponding improvements in EF and math problem-solving skills. They were estimated through comparing different time points within the same child and less susceptible to higher-level confounding. To improve precision in estimation, we also adjusted for person-mean and grand-mean centered simple reaction time (a broad indicator of cognitive development) and demographic covariates (child age, sex, and parent education). Given that each child was observed three times at maximum, we specified a random intercept and a fixed slope to characterize changes over time (the data did not support random slopes). We reviewed residual plots to check for distributional assumptions, which were met.

We report Cohen f^2 effect size to characterize the magnitude of the association between focal predictors (motor competence, MVPA) and outcomes. Cohen f^2 assesses variance in an outcome explained by each individual predictor by comparing changes in the total variance with or without the predictors. For Cohen f^2, values of .02, .15, and .35 have been suggested to index small, medium, and large effects, respectively (Cohen, 1988). It is unclear whether these conventions are appropriate for this area of study.

Results

Descriptive statistics and bivariate correlations between focal study variables are summarized in Tables 1 and 2 (more extensive correlations are provided in Tables S1 and S2 of the Supplemental Material). Descriptively, children demonstrated improvements in motor competence, EF, and math problem-solving skills across the fall, winter, and spring assessments, with more modest change in MVPA (potentially due to seasonal changes in outdoor activity). Although MVPA was weakly associated with EF and math problem-solving outcomes (*r*s = .02–.18), motor competence was strongly positively associated with EF and math problem-solving outcomes (*r*s = .36–.60) across all measurement occasions (see Table 2). The correlation between

MVPA and motor competence at each assessment occasion was small to moderate (*r*s = .18–.22; see Table S1).

We first estimated unconditional models to determine how much of the total observed variance for each outcome was attributable to between-classroom, between-child, and within-child components. For the math problem-solving score, 30%, 45%, and 25% of the total variation was attributable to between-classroom, between-child, and within-child differences, respectively. A similar pattern was evident for the overall EF (26%, 38%, and 36%) and the inhibitory control composites (19%, 39%, and 42%). The pattern for working memory differed, with comparatively more variation existing within children (12%, 25%, and 63% attributable to between-classroom, between-child, and within-child differences, respectively). These results indicated that appreciable variation existed between and within children for each outcome, which justified our investigation of within-child effects.

Table 3 summarizes the results from the four conditional models (one for each EF composite and one for math problem solving). For all three EF outcomes, the point estimates for motor competence were statistically significant at within- and between-child levels (all ps < .001). The within-child motor competence effect accounted for 13%, 9%, and 5%, respectively, of the variance in overall EF, inhibitory control, and working memory composites, with Cohen's f^2 ranging from .05 to .14 (small effects). The between-child motor competence effect explained 15%, 12%, and 5% variance in overall EF, inhibitory control, and working memory composites, respectively, equivalent to Cohen's f^2 of .18, .13, and .05 (small to moderate effects). For math problem solving, between- and within-child effects of motor competence were statistically significant ($p < .001$). The within-child motor competence effect explained 11% variance (f^2 = .12), and the between-child motor competence effect explained 13% variance (f^2 = .15) in the applied problems score. Neither the between-child effects nor the within-child effects for MVPA were statistically significant for any outcomes.

The previous results were based on multiply imputed data for all available observations, without restrictions. However, it has been recommended that at least 3 days of accelerometer data (with at least 6 hours of measurement per day) be used to obtain reliable estimates of habitual activity in preschool-aged children (Bingham et al., 2016; Hislop et al., 2014). In our sample, children averaged 3.6, 3.4, and 3.2 days of valid accelerometry data in weeks 1, 2, and 3, respectively. We conducted a sensitivity analysis that included re-estimating all models after excluding time-specific instances where a child did not meet recommended thresholds for accelerometer data. This resulted in a reduction of approximately two-hundred person-observations for each outcome in the sensitivity analyses (i.e., across all four outcomes, sensitivity models included 555-570 person-observations compared to 750-772 person-observations for the models that were described above). As summarized in Table S3, the point estimates for these models were comparable with those reported in Table 3 and the primary substantive conclusions were unchanged. The exception was that the within-child MVPA effect for math problem solving skills that was not statistically significant in the complete analysis (p = .065) crossed the threshold for statistical significance (p = .047) in sensitivity analysis.

Discussion

Most of the evidence that relates habitual engagement in MVPA to improved cognition, including EF, is derived from studies of adults and school-aged children (Singh et al., 2019). Comparatively less is known about the nature of these associations in early childhood. The rates of MVPA that were observed in this study are consistent with previous estimates of young children (Dias et al., 2019). Consistent with three recent studies, we did not observe a positive association between habitual levels of MVPA and EF skills in early childhood; however, we did replicate the well-established associations between motor skill development with EF and math problem-solving skills. Our study extends the current literature by simultaneously considering MVPA and motor competence, which are correlated, and by leveraging a repeated measures design to provide strong tests of within-child associations.

Early educators have been encouraged to increase the amount of time that young children spend being physically active (D'Onise et al., 2010). Although these efforts may have benefits for other aspects of healthy physical development (Ekelund et al., 2012), the prevailing idea that increased physical activity (especially MVPA) will facilitate cognitive or academic skill development does not have empirical support in early childhood. Future research will benefit from longitudinal studies that span the transition from early to middle childhood (e.g., ages 4 to 8 years) and that consider when and possibly for whom increased levels of MVPA contribute positively to EF skill development. For example, children's greater participation in recreational team sports in early elementary years may promote improvements in MVPA and EF skills. Moreover, the social and cognitive demands of team sports, which co-occur with increased opportunities for MVPA, may be especially relevant to the promotion of EF skills (Diamond & Ling, 2020).

Individual differences in early fine and gross motor skill development contribute to children's EF and pre-academic skill development (e.g., Cameron et al., 2016; Oberer et al., 2017). We extended these studies by demonstrating that the association between motor competence with EF and math problem-solving skills is not confounded by MVPA and by providing tests of within-child associations. While our study improves on many existing studies, it is still limited by a passive longitudinal design. Studies that employ experimental designs remain the gold standard for inferring whether improvements in motor competence are causally related to improvements in EF skills. Notably, two recent studies that used experimental designs demonstrated that exposing children to cognitively challenging motor activities induced improvements in their EF skills (Hudson et al., 2020; Mulvey et al., 2018). Although these studies were small (Ns = 53 and 107), of short duration (6-8 weeks), and varied in their focus (gross motor skills were targeted in Mulvey et al.; fine and gross motor skills in Hudson et al.), they provide a strong basis of inference regarding the causal association between children's engagement in cognitively challenging motor skills activities and improvements in EF skills. The convergence of results from our passive longitudinal study with these experimental studies is noteworthy.

Why might improvements in motor competence be associated with improvements in EF and math problem-solving skills? Individual differences in children's EF skills are commonly understood to reflect normative developmental changes in the structure and function of the prefrontal cortex (Petersen & Posner, 2012). It is less widely appreciated that the cerebellum, which has been historically understood to support motor functioning (e.g., control and balance), also supports emotional and cognitive functioning, including EF skills (Diamond, 2000; Mariën & Paquier, 2005; Miquel et al., 2019). Specifically, functional cerebellar–cortical networks (which involve "crosstalk" among the prefrontal cortex, the basal ganglia, the motor cortex, and the cerebellum) contribute to the development of EF skills in children (Riva et al., 2013). Koziol and colleagues posited that the cerebellum's primary function is to plan, monitor, and adaptively change movement in real time based on environmental contingencies (Koziol et al., 2014a; Koziol et al., 2014b; Koziol et al., 2012). They argued that children's early motor development represents a cardinal set of challenges (i.e., the *first* goal-directed activities), and the resolution of these challenges contributes to the emergence of cerebellar–cortical networks that facilitate early EF skill development. Hence, the normative improvements in motor skill development that we observed here may have enhanced EF skill development by promoting the organization and efficiency of cerebellar–cortical networks. Improvements in EF skills may facilitate children's ability to benefit from ongoing math instruction and learning opportunities in early childhood classrooms.

Our study is characterized by five primary limitations. First, our use of accelerometry to measure MVPA was limited to 5 weekdays of assessment (Monday through Friday). The decision to limit data collection to weekdays was pragmatic (i.e., all data could be collected in a 1-week period for each preschool at each assessment period). The omission of accelerometry data over the weekend may have contributed to inaccuracy of MVPA estimates. Second, we used a brief motor assessment that does not support a distinction between fine and gross motor skill development. Testing for within-person contributions of fine and gross motor skill development is an important direction for future research. Third, we completed three assessments in a single preschool year, with approximately 6 months spanning the first and last assessments. Future studies will benefit from a longer time span to better characterize intra-individual changes in children's MVPA, motor competence, EF, and math problem-solving skills (i.e., longer time periods may support models that include random effects for intercepts and slopes). Fourth, despite our emphasis on within-child associations, we used a passive longitudinal design and a convenience sample. Our results are exploratory in nature (they do not support strong causal inferences), and questions about the generalizability of conclusions remain. Fifth, we focused on unidirectional associations between motor competence and MVPA with EF skills. Future studies with larger samples and that span longer periods of time will be better suited to testing potential bidirectional associations between motor competence and EF skills.

Historical characterizations of children’s physical health and cognition as distinct domains of development are slowly being replaced by an improved understanding of their interrelations (Diamond, 2000; Glenberg et al., 2013). Our study was motivated by an effort to integrate studies that have tended to focus on physical activity intensity or motor skill development, separately, in early childhood. Our study adds to growing evidence that motor competence uniquely and robustly contributes to EF and math problem-solving skill development in early childhood. The interrelated nature of early motor and cognitive development holds promise for the development of novel interventions that support young children’s EF and pre-academic skills.

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Table 1

Descriptive Statistics for Time Varying Predictor and Outcome Variables

Variable	Period	*N*	*M (SD)*
Motor competence	Week 1	265	21.10 (11.19)
	Week 2	267	25.93 (11.38)
	Week 3	243	28.45 (11.39)
	Person average	283	24.58 (10.71)
Proportion time in MVPA	Week 1	249	11.49 (4.05)
	Week 2	251	11.50 (3.68)
	Week 3	231	12.42 (4.34)
	Person average	276	11.64 (3.38)
Executive function composite	Week 1	263	59.07 (14.07)
	Week 2	265	65.19 (14.31)
	Week 3	244	68.53 (14.59)
	Person average	282	63.52 (13.15)
Inhibitory control composite	Week 1	257	58.96 (21.11)
	Week 2	262	65.59 (20.43)
	Week 3	241	69.81 (20.23)
	Person average	281	63.63 (18.57)
Working memory composite	Week 1	253	56.30 (14.75)
	Week 2	261	62.20 (12.92)
	Week 3	236	64.25 (13.53)
	Person average	281	60.15 (11.45)
Math problem solving	Week 1	263	390.84 (24.24)
	Week 2	257	400.62 (20.81)
	Week 3	238	404.15 (23.64)
	Person average	283	396.93 (22.32)
Simple reaction time	Week 1	262	1.25 (.32)
	Week 2	264	1.09 (.29)
	Week 3	242	1.06 (.27)
	Person average	282	1.14 (.27)

Note. MVPA = Moderate to vigorous physical activity.

Table 2

Bivariate Correlations between Time-Varying Predictors and Outcome Variables

		Motor competence	MVPA	SRT
		r	*r*	*r*
EF composite	Week 1	0.60	0.09	-0.45
	Week 2	0.60	0.15	-0.51
	Week 3	0.57	0.03	-0.50
	Person average	0.68	0.16	-0.59
Inhibitory control	Week 1	0.55	0.11	-0.41
	Week 2	0.55	0.09	-0.44
	Week 3	0.51	0.03	-0.46
	Person average	0.64	0.16	-0.55
Working memory	Week 1	0.40	0.02	-0.28
	Week 2	0.36	0.17	-0.38
	Week 3	0.42	0.08	-0.32
	Person average	0.50	0.11	-0.46
Math Problem Solving	Week 1	0.53	0.13	-0.45
	Week 2	0.60	0.04	-0.46
	Week 3	0.60	0.18	-0.35
	Person average	0.64	0.15	-0.50

Note. EF = Executive function; MVPA = Moderate to vigorous physical activity; SRT = Simple reaction time

Table 3

Summary of Regression Coefficients from Conditional Mixed Linear Models

	EF composite	IC composite	WM composite	Math Prob. Solving
Fixed effect				
Intercept	63.46 (.68)***	63.66 (.90)***	60.21 (.62)***	397.37 (1.30)***
Within-child MC	.54 (.06)***	.68 (.09)***	.42 (.07)***	.74 (.08)***
Within-child MVPA	.02 (.06)	.05 (.10)	.02 (.09)	.18 (.09)
Within-child SRT	-7.35 (2.28)**	-8.33 (3.23)*	-6.48 (2.39)**	-4.95 (2.26)*
Between-child MC	.56 (.07)***	.74 (.10)***	.37 (.07)***	.81 (.11)***
Between-child MVPA	-.05 (.12)	-.07 (.18)	-.000 (.12)	.16 (.22)
Between-child SRT	-11.18 (2.75)***	-14.80 (3.93)***	-7.60 (2.62)**	-9.66 (4.51)*
Age	.08 (.11)	.08 (.17)	.07 (.11)	.37 (.21)
Female	2.09 (1.14)	3.30 (1.70)	1.06 (1.18)	2.68 (2.04)
Parent education	.10 (.61)	-.08 (.91)	.37 (.63)	1.66 (1.17)
Random effect				
Level 1 (repeated)	66.81***	175.50***	117.08***	121.94***
Level 2 (person level)	50.32***	106.71***	40.70***	186.10***
Level 3 (class level)	10.77	9.55	3.50	515.50*

Note. * $p < .05$, ** $p < .01$, *** $p < .001$. EF = Executive function; IC = Inhibitory control; WM = Working memory; MC = Motor competence; MVPA = Moderate to vigorous physical activity; SRT = Simple reaction time. Between-child effects refer to the effects of differences that existed between children. Within-child effects refer to the effects of changes in a predictor within a child across measurement occasions.