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Article

Longitudinal Associations of Body Fatness and Physical Fitness with Cognitive Skills in Preschoolers

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Abstract: The importance of cognitive health for academic success is well-recognized. However, longitudinal data regarding the associations of body fatness, physical fitness and cognition are relatively scarce and mixed. The purpose of this study was to investigate whether body fatness, cardiorespiratory fitness (CRF) and muscular fitness (MF) in preschool are associated with cognitive skills in first grade at school. 133 South Estonian children aged 6-7 years were recruited from 13 kindergartens and again at 7-8 years when they had entered school. Body fat percentage (BF%), CRF, MF as the mean of z-scores of relative handgrip strength and standing long jump tests, and cognitive skills (verbal, conceptual, perceptual) were studied. There were no associations between BF% and CRF in preschool with perceptual, conceptual or verbal skills in school in boys and girls. In boys, higher MF in preschool predicted higher verbal skills ($\beta = 0.293$, $p = 0.021$) in school after adjustment for confounders. Cognitive skills at baseline seemed predominantly predict later cognitive performance in school. In conclusion, higher muscular fitness in preschool predicted better verbal skills in first grade at school in boys but not in girls. Body fatness and cardiorespiratory fitness in preschool were not associated with cognitive skills in school.

Keywords: body fatness; cardiorespiratory fitness; muscular fitness; cognitive skills; preschool children

1. Introduction

There are studies to suggest inverse relationships between body fatness and cognitive abilities in early childhood [1-3], while other investigations have not found associations between body fatness and cognitive abilities [2,4,5]. For example, Haapala et al. [3] found a negative relationship between body fat percentage (BF%) with reading fluency and reading comprehension in 6-8-year-old boys. Martin et al. [2] observed that higher body mass index (BMI) in 3-year-old boys was associated with worse visuospatial skills, yet not with expressive language skills or reasoning skills at 5 years. Flores et al. [5] reported that obesity was not associated with arithmetical performance among 3-6-year-old children. In addition, previous studies disagree whether higher regional or whole-body fat content predict worse cognitive performance [1,6,7]. Higher abdominal fat deposition was associated with worse relational memory but not with item memory in children with overweight or obesity at 7-9 years. Whole-body fat content was not associated with relational or item memory. Also, no associations between body fatness parameters and memory tasks existed in children with healthy weight [6]. Likewise, Raine et al. [7] found that especially in 8-9-year-old children with obesity, the reduction only in visceral adipose tissue within 9 months was associated with increased inhibitory control [7]. However, higher whole-body and abdominal body fatness predicted inferior executive function, resistance to distraction, and gestalt processing among 7-11-year-old children with overweight [1]. Therefore, very few observational studies have checked the sex-specificity of these associations, finding negative association between body fatness and cognition among preschool-aged [2] and first-grade boys [3] but not in girls. It has been found that the decrease in obesity status had

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positive associations with some cognitive skills in preschool-aged girls [2]. Regarding to the mixed results and the paucity of longitudinal studies [2,4], current study aims to explore the possible longitudinal associations between body fatness in preschool-aged boys and girls separately with their cognitive skills in school.

There is lack of uniformity in the findings on the associations between physical fitness (PF) and cognition in children and adolescents, where cardiorespiratory fitness (CRF) or muscular fitness (MF) seem to associate with some cognitive skills, but then not with others. For example, in 4-6-year-old children CRF at baseline was related to improvements in attention and not with working memory during 9-month period [8]. As well, 9-year-old children with higher CRF had better visual discrimination [9] but not better reaction time compared to children with lower CRF [10]. Moreover, CFR at 6–9 years did not predict non-verbal cognitive performance two years later in boys or girls [4]. Regards to MF, neither standing long jump (SLJ) nor handgrip strength at 7-9 years predicted non-verbal cognitive performance further in childhood and adolescence [11]. Meanwhile, Syväoja et al. [12] reported that higher MF was indirectly associated with higher math outcomes through visuospatial working memory only among adolescent girls [12]. In addition to contradictory findings described above, the number of studies on the associations between CRF, SLJ and handgrip strength either addressed separately or as a compound MF score in children is relatively small, therewith lack of longitudinal studies in preschoolers [8,13] or primary schoolers [4,11,14]. Accordingly, it is important to study the associations of CRF and MF in preschool-aged boys and girls with their cognitive skills in school.

Our work intends to extend the understanding of the relationships between body fatness and physical fitness of preschoolers with their verbal, conceptual and perceptual skills in school, as cognitive skills me have significant educational, occupational and health outcomes [15]. The specific aim of the present study was to investigate whether body fatness, cardiorespiratory fitness and muscular fitness in preschool are associated with cognitive skills in first grade at school in boys and girls.

2. Materials and Methods

2.1. Participants

A two-phased longitudinal study was conducted in Tartu and nearby counties in Estonia. In the first phase of the study from March to May 2016, children at 6-7 years in their final year of kindergarten were recruited from 13 kindergartens. The parents of children from 400 families obtained written information about the study with invitation to participate. Written consent and assent to participate in the study were given by 284 families. The second study phase was carried out from March to September 2017, when children aged 7-8 years had entered the first grade in school. The same families who participated in the first study phase were contacted and asked to participate again. 200 families gave their consent and assent to participate. The measurements were performed either in the kindergarten (first phase) or the school settings (second phase). Complete data on variables used in the analyses on cognitive skills associations were available for 133 children (67 boys, 66 girls). Additionally, each parent completed a short questionnaire reporting about the educational attainment (categorized as basic, general secondary/vocational or higher). The degree of more educated parent was used in the analyses. The study was approved by the Medical Ethics Committee of the University of Tartu (reference 254/T-13 and 266/T-8), and is in accordance with the ethical standards of the Declaration of Helsinki.

2.2. Assessment of Body Composition

Body height and mass were measured using calibrated medical digital scales (A&D Instruments, Abington, UK) and portable stadiometer (Seca 213, Hamburg, Germany) to the closest 0.05 kg and 0.1 cm, respectively, with the participant wearing light clothing without shoes. BMI was calculated as body mass (kg) divided by body height squared (m^2). Overweight and obese subjects were defined by age-specific BMI cutoff points [16]. Skinfold thicknesses at the triceps and subscapular site of the

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body were measured in triplicate with a Holtain caliper (Crymmych, UK) to the nearest 0.2 mm based on standardized procedures [17,18]. BF% was calculated from triceps and subscapular skinfold thicknesses using the equations by Slaughter et al. [19] for 6-17-year-old children and youth.

2.3. Assessment of Physical Fitness

Standardized fitness test battery was used to investigate the children's physical fitness parameters [20,21]. To CRF, 20 m shuttle run test was applied. Participant was instructed to run between two marked lines over a 20 m course in time with taped audio signals. The initial velocity was 8.5 km/ h, which increased by 0.5 km/h after each min. When participant could no longer keep up with the pace, the last lap number announced was recorded when scoring the test. The test was performed once [21].

To determine upper-limb muscular fitness (MF), handgrip strength test with digital dynamometer (Digital TKK 5401, Grip D, Takei, Tokyo) was applied. Children squeezed dynamometer gradually and continuously as hard as they could at least 2-3 s, the elbow was held in extended position, avoiding the contact of dynamometer with other parts of the body, except the hand being measured. The best value of the two non-consecutive trials of each hand was taken into consideration, and the mean of both hands was calculated (kg) [21]. Relative upper-limb MF per kg of body mass [handgrip strength (kg/kg)] was used [22].

To determine lower-limb MF, SLJ test (cm) was used, where the child stood behind the line, legs opened shoulder width and had to jump as far as possible with feet together and remaining upright when landing; arm swing was allowed in take-off [21]. The best of two attempts was used in the analyses [23].

A MF score (muscular fitness z-score) was calculated as the combination of sex-specific standardized values of relative handgrip strength (kg/kg) and standing long jump (cm). These variables were standardized as follows: z-score = (value-mean)/SD. The muscular fitness z-score was calculated as the mean of the 2 standardized scores (relative handgrip strength and standing long jump) [22].

2.4. Assessment of Cognitive Skills

Cognitive skills were tested by modified Boehm Test of Basic Concepts – Third Edition (Boehm-3) [24], which has been adjusted and validated for Estonian children [25,26]. Boehm-3 was designed to assess young children's understanding of the basic relational concepts that are important for language and cognitive development, and for success in school across all learning areas [24]. The test consisted of three parts: conceptual, verbal and perceptual skills. Conceptual skills were tested to assess the child's understanding of the concepts of adverbs and the place and location of objects. The child's understanding of the Estonian language was tested to assess verbal skills. During both tests, the child had to listen to the researcher's instructions and mark the picture that matched the sentence they were given. Child's perception was assessed by the means of progressive matrix test, which involved choosing the right picture to complete a regular sequence of pictures [25,26]. Child was scored one point for every right answer, and the scores were presented for each of the three categories.

2.5. Statistical Analysis

The analyses were performed separately in boys and girls. Continuous variables were checked for normality before the analysis using the Shapiro-Wilk test. Basic characteristics between boys and girls were compared using the Student t-test for normally distributed continuous variables, the Mann-Whitney U test for other continuous variables, and the Chi-square test for categorical variables (prevalence of overweight and obese and parental education). The associations of BF%, CRF, MF z-score in preschool with verbal, conceptual and perceptual skills in school were examined using multiple linear regression analysis. Baseline values of exposures (BF%, CRF, MF z-score), baseline outcomes (verbal, conceptual and perceptual skills), age and parental education were applied in the

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adjusted model. Adjustments were done for well-documented confounding variables such as age, parental education and baseline cognitive skills [4,8,27]. The variance inflation factors between variables were less than five, denoting that collinearity was not a concern. A significance level of $p < 0.05$ was set. The analyses were conducted using SPSS software (version 20.0; SPSS, Inc., Chicago, IL, USA).

3. Results

3.1. Baseline Characteristics of Children

Boys were taller ($p < 0.001$), heavier ($p = 0.010$), and greater handgrip strength ($p = 0.007$) than girls. Boys also had a lower BF% than girls ($p < 0.001$) (Table 1).

Table 1. Basic characteristics.

Variable	Boys	Girls	p
Age (years)[1]	7 (1)	6 (1)	0.240
Height (cm)	127 (5.4)	124 (5.7)	**<0.001**
Weight (kg)[1]	26 (6.5)	23.5 (5.6)	**0.010**
BMI (kg/m²)[1]	16.1 (2.5)	15.4 (2)	0.323
Prevalence of overweight and obese (%)	17.9	9.9	0.170
BF%	19.8 (6.3)	21.4 (5.9)	**<0.001**
Parental education (%)			0.765
Lower secondary	1.4	3	
Post-secondary or vocational	15.7	17.9	
University degree	82.9	79.1	
Physical fitness tests			
20 m shuttle run (laps)[1]	18 (19.3)	18.5 (8.5)	0.383
Handgrip strength (kg)[1]	11.5 (3)	9.9 (2.6)	**0.007**
Handgrip strength/weight (kg/kg)	0.4 (0.1)	0.4 (0.1)	0.299
Standing long jump (cm)	125 (18)	119 (18)	0.061
Muscular fitness z-score	0.01 (0.5)	-0.01 (0.5)	0.797
Modified Boehm-3 test			
Progressive matrix (max score 10)[1]	8 (3)	7 (5)	0.201
Conceptual skills (max score 17)[1]	14.5 (2)	14 (2.8)	0.418
Verbal abilities (max score 9)[1]	5.5 (1)	6 (1)	0.650

Data are from the Student t-test or the Mann–Whitney U-test, or the Chi-square test for categorical variables and are presented as means (standard deviations), medians (interquartile range[1]), or percentages (%). BMI - body mass index, BF% - body fat percentage. Significant associations are marked in bold.

3.2. Associations of BF% in Preschool and Cognitive Skills in School

In boys, BF% in preschool was not associated with cognitive skills in school. In the adjusted model, verbal ($R^2 = 0.217$, $p = 0.002$) and perceptual ($R^2 = 0.300$, $p < 0.001$) skills in preschool were positively associated with verbal and perceptual skills (both $p < 0.001$) in school, respectively (Table 2).

In girls, BF% in preschool was negatively associated with perceptual skills ($R^2 = 0.070$, $p = 0.036$) in school. In the adjusted model, conceptual ($R^2 = 0.195$, $p = 0.004$) and verbal ($R^2 = 0.206$, $p = 0.003$) skills in preschool were positively associated with conceptual ($p = 0.002$) and verbal ($p = 0.001$) skills in school, respectively. Additionally, age in preschool was negatively associated with verbal skills ($p = 0.024$) in school. And, higher parental educational attainment in preschool ($R^2 = 0.292$, $p < 0.001$) was associated with higher perceptual skills ($p < 0.001$) in school (Table 2).

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3.3. Associations of CRF in Preschool and Cognitive Skills in School

In boys, CRF in preschool was positively associated with perceptual skills ($R^2 = 0.081$, $p = 0.033$) in school. In the adjusted model, verbal ($R^2 = 0.151$, $p = 0.018$) and perceptual ($R^2 = 0.259$, $p < 0.001$) skills in preschool were positively associated with verbal ($p = 0.003$) and perceptual skills ($p < 0.001$) in school, respectively (Table 2).

In girls, CRF in preschool was positively associated with conceptual skills ($R^2 = 0.073$, $p = 0.039$) in school. In the adjusted model, conceptual ($R^2 = 0.220$, $p = 0.004$), verbal ($R^2 = 0.166$, $p = 0.014$) skills and parental education ($R^2 = 0.278$, $p = 0.001$) in preschool were positively associated with conceptual ($p < 0.001$), verbal ($p = 0.013$) and perceptual skills ($p < 0.001$) in school, respectively. In addition, older age in preschool was associated with lower verbal ($p = 0.023$) and perceptual ($p = 0.022$) skills in school, respectively (Table 2).

3.4. Associations of Muscular Fitness in Preschool and Cognitive Skills in School

In boys, MF in preschool was positively associated with verbal skills ($R^2 = 0.074$, $p = 0.024$) in school. In the adjusted model, the association between MF in preschool and verbal skills in school remained positive ($p = 0.021$). Additionally, conceptual ($R^2 = 0.095$, $p = 0.066$), verbal ($R^2 = 0.236$, $p = 0.002$) and perceptual ($R^2 = 0.248$, $p = 0.001$) skills in preschool were positively associated with conceptual ($p = 0.048$), verbal ($p = 0.004$) and perceptual skills ($p < 0.001$) in school, respectively (Table 2).

In girls, MF in preschool was not associated with cognitive skills in school. In the adjusted model, higher conceptual ($R^2 = 0.208$, $p = 0.005$), verbal ($R^2 = 0.214$, $p = 0.004$) skills and parental education ($R^2 = 0.298$, $p < 0.001$) in preschool were associated with higher conceptual ($p = 0.001$), verbal ($p = 0.008$) and perceptual skills ($p < 0.001$), respectively. In addition, older age in preschool was associated with lower perceptual ($p = 0.009$) skills in school (Table 2).

Table 2. Multiple regression analysis predicting children's cognitive skills in school. Associations of body fatness, physical fitness in preschool and cognitive skills in school.

	Cognitive skills in school											
	Conceptual skills				**Verbal skills**				**Perceptual skills**			
	Boys (n=66)		**Girls (n=67)**		**Boys (n=66)**		**Girls (n=66)**		**Boys (n=66)**		**Girls (n=67)**	
Variables in preschool	**β**	**p**	**β**	**p**	**β**	**p**	**β**	**p**	**β**	**p**	**β**	**p**
Unadjusted												
BF%	-0.075	0.599	0.221	0.082	-0.155	0.227	-0.016	0.901	-0.079	0.539	-0.265	**0.036**
Adjusted												
BF%	0.033	0.801	0.190	0.130	-0.082	0.500	-0.040	0.746	-0.172	0.139	-0.184	0.119
Age	0.168	0.199	-0.092	0.449	0.064	0.592	-0.284	**0.024**	-0.151	0.186	-0.203	0.081
Cognitive skills*	0.177	0.195	0.396	**0.002**	0.467	**<0.001**	0.416	**0.001**	0.574	**<0.001**	0.189	0.103
Education	0.254	0.073	0.149	0.238	0.113	0.358	0.069	0.579	-0.166	0.153	0.493	**<0.001**
Unadjusted												
CRF	-0.070	0.607	0.270	**0.039**	0.033	0.807	0.164	0.213	0.285	**0.033**	0.067	0.617
Adjusted												
CRF	-0.123	0.367	0.065	0.637	0.034	0.791	-0.039	0.786	0.227	0.059	-0.052	0.696
Age	0.182	0.190	-0.131	0.307	0.091	0.500	-0.306	**0.023**	-0.129	0.290	-0.288	**0.022**
Cognitive skills*	0.291	0.061	0.450	**<0.001**	0.419	**0.003**	0.341	**0.013**	0.535	**<0.001**	0.201	0.109
Education	0.037	0.805	0.140	0.329	0.073	0.574	0.084	0.564	-0.085	0.471	0.510	**<0.001**
Unadjusted												
Muscular fitness	-0.150	0.270	0.056	0.674	0.302	**0.024**	-0.207	0.116	0.182	0.180	0.152	0.252
Adjusted												
Muscular fitness	-0.142	0.289	0.021	0.875	0.293	**0.021**	-0.223	0.102	0.097	0.432	0.255	0.051
Age	0.155	0.255	-0.110	0.419	0.127	0.319	-0.229	0.095	-0.090	0.467	-0.347	**0.009**
Cognitive skills*	0.303	**0.048**	0.460	**0.001**	0.380	**0.004**	0.349	**0.008**	0.531	**<0.001**	0.219	0.072
Education	0.042	0.776	0.140	0.294	0.081	0.515	0.084	0.512	-0.073	0.551	0.448	**<0.001**

*Baseline cognitive skill (conceptual, verbal or perceptual skill) score was entered in the model with respective cognitive skill at follow-up. β - standardized regression coefficient; BF% - body fat percentage; CRF - cardiorespiratory fitness. Significant associations are marked in bold.

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4. Discussion

This study aimed to investigate whether body fatness, and cardiorespiratory fitness and muscular fitness in preschool are associated with cognitive skills in first grade at school. The main findings were: 1) BF% in preschool was not associated with conceptual, verbal and perceptual skills at first grade in school in boys and girls after adjustment for potential confounding factors; 2) CRF in preschool was not associated with conceptual, verbal and perceptual skills in school in boys and girls when adjusted for possible confounding factors; 3) higher MF in preschool was associated with higher verbal skills in school only in boys after adjustment for potential confounding factors. It was also observed that cognitive skills at preschool were frequently positive predictors of cognitive performance at follow-up in first grade at school both in boys and girls, although there were some sex differences. Additionally, higher parental educational attainment at baseline was associated with higher perceptual skills at follow-up in girls. Correspondingly, Riso et al. [28] concluded that preschoolers from more highly educated families had higher conceptual and verbal skills. Interestingly, younger age in preschool was occasionally associated with higher verbal or perceptual skills in school only among girls.

In unadjusted analysis we found that skinfold thickness derived BF% in preschool was negatively associated with perceptual skills in school among girls. However, once adjusted for confounding factors, such as age, parental education and cognitive skill at baseline, no associations between BF% in preschool and conceptual, verbal or perceptual skills at first grade in school in boys or girls existed. Prior studies in children show rather mixed results between BF% or obesity and cognitive measures [1-4,7,29]. Although Haapala et al. [3] reported a weak inverse association between dual-energy x-ray absorptiometry (DEXA) measured BF% with reading fluency and reading comprehension among 6-8-year-old boys once adjusted for age and parental education, these sex-specific associations were largely explained by differences in motor performance between boys with lower and higher BF% [3]. In a longitudinal study, in boys with obesity aged 3 years was associated with worse pattern construction (visuospatial skills), but not naming vocabulary (expressive language skills) or reasoning skills (picture similarity) at 5 years after controlling for several confounding factors. “Growing out” of obesity between 3 and 5 years had a positive association with reasoning skills in girls at 5 years [2]. In children at 8-9 years, the degree of reduction only in visceral adipose tissue during 9 months was associated with increased inhibitory control. These associations were particularly obvious among obese children [7]. However, Davis and Cooper [1] showed that both whole-body and abdominal body fatness were negatively associated with executive function, resistance to distraction, and gestalt processing in children with overweight aged 7-11 years after controlling for race, sex, and primary caregiver's education level [1]. Consistent with present study, Haapala et al. [4] demonstrated that bioelectrical-impedance-method-detected BF% at 6-9 years was not associated with non-verbal reasoning skills two years later in either sex after controlling for cognitive skills at baseline. Meanwhile, one study even suggested that not overweight but underweight predicted worse cognitive and academic performance once adjusted for early behavior, cognitive skills and socioeconomic status at early age [29]. The variability in the results among studies might come from differences in the weight status of studied children, different methods applied to assess body composition, different cognitive tasks involved in the studies, sociodemographic differences across countries, and differences in adjustments for confounders. In current study, body fatness in preschool was not independently associated with cognitive skills in school in boys or girls.

In our study, higher CRF in preschool predicted higher conceptual skills in girls and higher perceptual skills in boys a year later. However, these associations disappeared after controlling for confounding variables, such as age, parental education and cognitive skill at baseline. Higher number of laps in 20 m shuttle run test in preschool was associated with better perceptual skills in school. However, this association disappeared once adjusted for sex and age, and controlling for maternal education and sports club attendance did not change this association [13]. In general, there seems to be a lack of consistency in the studies investigating the associations between CRF and cognition at young age. A cross-sectional study has shown that CRF was linked to better working memory

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performance in boys but not in girls aged 8-11 years [30]. Children at 9 years with high CRF levels on 20 m shuttle run test exhibited superior performance in a visual discrimination task [9] and performed more accurately the tasks involving inhibition compared to children in the low fitness group, whereas no group differences were observed for reaction time [10]. Longitudinal research has also demonstrated mixed findings on the relationships between CRF and cognitive skills. Specifically, Chaddock et al. [14] showed that children with higher peak oxygen consumption at 9-10 years had superior response accuracy in compatibility conditions, yet not in incompatibility conditions on flanker test at baseline and follow-up testing one year later, compared with lower-fit children. In addition, a shorter compatible and incompatible reaction time for higher-fit children was observed [14]. Niederer et al. [8] reported that baseline 20 m shuttle run test results we associated with improvements in attention but not with working memory during 9-month period among children aged 4-6 years after controlling for several confounding factors [8]. In order to explore the association between CRF and cognition, Haapala et al. [4] applied a Raven's progressive matrices test (RPM) test, that has methodological similarities to non-verbal perceptual reasoning abilities testing applied in our study. Comparably to our results, cycle ergometer-assessed exercise capacity at 6–9 years was not associated with RPM score, nor with the change in RPM score during 2-year follow-up in boys or girls after adjustment for age, study group and baseline RPM score. In accordance with current study, Haapala et al. [4] observed that cognitive performance at baseline was a strong predictor of cognitive functioning two years later among both sexes.

Differences in CRF and cognition testing methodology, and confounding variables included may modify the associations between CRF and cognitive performance, and hence clear up the observed diversity in the results between the studies. However, longitudinal research on the associations between other fitness components except CRF and cognitive performance is limited. Current study demonstrated that higher MF in preschool was associated with higher verbal skills in school independent of confounders in boys, with no such association observed for females. Syväoja et al. [12] detected that MF (the sum of abdominal and upper-body muscle strength) had a positive indirect association with math outcomes through visuospatial working memory among girls aged 12-17 years, and not in boys. Additionally, the indirect path from compound fitness z-score (including the six-minute-run, SLJ and the jumping sideways task) via executive functions among 5–7-years preschoolers on mathematical and reading achievement 18 months later in school has been reported [31]. While higher SLJ relative to fat-free mass in preschool, but not relative handgrip strength parameters were associated with superior perceptual abilities in school [13]. Lima et al. [11] found that at 7-9 years from all the child's PF components tested, only speed and agility fitness (50 m shuttle run test) and manual dexterity and upper-limb movement speed (box and block test) were associated with later cognitive performance on RPM at middle childhood and at adolescence, respectively after controlling for child's age, sex, pubertal status, intervention group, maternal age, family income, parity and gestational age at birth. However, 50 m shuttle run and box and block tests were no longer related to cognition in the adjustment model including prenatal, neonatal and child fitness factors. Baseline SLJ or handgrip strength or sit-ups did not predict later cognitive performance [11].

This study has some limitations. Our study was not a randomized controlled trial; hence, we cannot infer the causal association between variables. Compared with prior studies, our relatively smaller sample size may also explain the non-significant results reported in the current study. However, the number of participants in our study was comparable to that in similar investigations in this area [3,5,30,31]. Body fat content was measured indirectly by measuring skinfolds, and although Slaughter equation for determining BF% has reasonably strong validity with DEXA in children, still the gold standard for measuring body fat composition in children is DEXA [32]. Although we adjusted our statistical analysis for some confounding factors, the results may be confounded by other variables, such as genetic, dietary or socioeconomic factors, we cannot exclude the possibility of residual confounding factors. On the other hand, we consider longitudinal design and the application of standardized tests to assess PF and cognitive abilities as major strengths of our study.

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5. Conclusions

We extended previous research by demonstrating that in our model, where several independent variables were entered simultaneously to predict later perceptual, conceptual or verbal skills in school, cognitive performance at baseline seems largely predict later cognitive functioning and only the direct influence of higher MF compound score on verbal abilities remained significant among boys.

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Institutional Review Board Statement: Ethical approval was obtained from the Medical Ethics. Committee of the University of Tartu, Estonia, with the ethical approval code number reference 254/T-13 and 266/T-8, and was made in accordance with the Helsinki Declaration (date: 19. Jan 2015 and 16. Jan 2017).

Informed Consent Statement: Written informed consent was provided by all participants.

Data Availability Statement: The datasets used in this study are available from the corresponding author upon reasonable request.

Conflicts of Interest: The authors declare no conflicts of interest.

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