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# Mediating effects of motor performance, cardiorespiratory fitness, physical activity, and sedentary behaviour on the associations of adiposity and other cardiometabolic risk factors with academic achievement in children

**Running title:** Cardiometabolic risk and academic achievement

**Key words:** children, obesity, metabolic syndrome, fitness, academic performance

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## ABSTRACT

We investigated the associations of cardiometabolic risk factors with academic achievement and whether motor performance, cardiorespiratory fitness, physical activity, or sedentary behaviour mediated these associations. Altogether 175 children 6–8years-of-age participated in the study. We assessed body fat percentage (BF%), waist circumference, insulin, glucose, triglycerides, HDL cholesterol, and systolic and diastolic blood pressure, leptin, alanine aminotransferase, and gamma-glutamyltransferase (GGT). Reading fluency, reading comprehension, and arithmetic skills were assessed using standardized tests. Speed/agility, balance, and manual dexterity test results were used to calculate motor performance score and physical activity was assessed by combined heart rate and movement sensor and cardiorespiratory fitness by maximal cycle ergometer test. In boys, BF% was inversely associated with reading fluency ( $\beta=-0.262$ ,  $P=0.007$ ) and reading comprehension ( $\beta=-0.216$ ,  $P=0.025$ ). Motor performance mediated these associations. Leptin was inversely related to reading fluency ( $\beta=-0.272$ ,  $P=0.006$ ) and reading comprehension ( $\beta=-0.287$ ,  $P=0.003$ ). The inverse association of leptin with reading fluency was mediated by motor performance. In girls, GGT was inversely associated with reading fluency independent of confounders ( $\beta=-0.325$ ,  $P=0.007$ ). The inverse association of BF% with academic achievement among boys was largely explained by motor performance. Leptin in boys and GGT in girls were inversely associated with academic achievement independent of confounding factors.

## INTRODUCTION

Overweight and obese children have been found to have poorer cognition than their normal weight counterparts (Kamijo, Pontifex, et al., 2012). Similarly, metabolic syndrome (MetS) may impair brain development and cognition among children and adolescents (Yates, Sweat, Yau, Turchiano, & Convit, 2012). However, the evidence on the associations of measured body fat percentage (BF%) and MetS with academic achievement in children is limited.

Overweight, obesity, and BF% have been inversely associated with cognition and academic achievement in children and adolescents in most but not all studies (Davis & Cooper, 2011; Kavanagh et al., 2011; Reinert, Po'e, & Barkin, 2013). Hypertension and insulin resistance also have been linked to impaired brain structures, cognition, and academic achievement among children and adolescents (Yates et al., 2012). Moreover, adolescents with elevated plasma leptin concentration have been found to have poorer academic achievement than those with lower concentration (Correa-Burrows et al., 2016). Increased liver enzymes gamma-glutamyltransferase (GGT) and alanine aminotransferase (ALAT) as markers of non-alcoholic fatty liver disease (NAFLD) have been found to be integral part of MetS in children (Viitasalo et al., 2012b), but there are no previous studies on their associations with cognition or academic achievement in children. However, increased concentration of GGT have been found to increase risk of dementia in older adults (Kunutsor & Laukkanen, 2016). Furthermore, NAFLD has been linked to decreased brain volumes and cerebral blood flow in middle-aged adults (VanWagner et al. 2017).

Adiposity and other cardiometabolic risk factors, motor performance, cardiorespiratory fitness, physical activity, and sedentary behaviour are interrelated (Collings et al., 2017; Haapala et al., 2016; Robinson et al., 2015; Väistö et al., 2014). Motor performance (Haapala et al., 2015), but not cardiorespiratory fitness (Khan et al., 2016), has been found to modify the inverse association of adiposity with cognition in children. However, few previous studies have investigated the modifying and mediating effects of motor performance, cardiorespiratory fitness, physical activity, or sedentary

behaviour on the associations of adiposity and other cardiometabolic risk factors with academic achievement in children.

We investigated the associations of BF%, the clustered cardiometabolic risk score, Homeostatic Model Assessment for Insulin Resistance (HOMA-IR), leptin, GGT, and ALAT with academic achievement in children. We also studied the modifying and mediating effects of motor performance, cardiorespiratory fitness, moderate-to-vigorous physical activity (MVPA), and sedentary behaviour on these associations.

## **METHODS**

### **Study design and study population**

Data for the present analyses were obtained from the Physical Activity and Nutrition in Children (PANIC) Study and the First Steps Study, two independent studies conducted simultaneously among primary school children in the City of Kuopio, Finland (Haapala et al., 2014). Altogether 207 children from the City of Kuopio participated in both the PANIC Study and the First Steps Study. Data on BF%, other cardiometabolic risk factors, and confounding factors were derived from the PANIC Study in Grade 1 and data on reading and arithmetic skills at the end of Grades 1–3 were received from the First Steps Study. Complete data on variables used in the main analyses on the associations between BF% and academic achievement were available for 175 children (106 boys, 69 girls). Complete data on variables used in the main analyses on the associations between other cardiometabolic risk factors and academic achievement were available for 174 children (103 boys, 71 girls). Children who were included in the study sample were more likely boys, had poorer cardiorespiratory fitness, lower levels of MVPA, and higher levels of objectively measured sedentary time than children who were excluded because of missing data ( $P < 0.05$ ). The PANIC Study protocol was approved by the Research Ethics Committee of the Hospital District of Northern Savo, Kuopio, and the First Steps Study protocol was approved by the Research Ethics Committee of the University of Jyväskylä. All participating children and their parents provided written informed consent.

## **Assessment of academic achievement**

Academic achievement was assessed at the end of Grades 1–3 using group-administered tests in classrooms by trained research assistants supervised by a senior researcher. Research assistants explained the tests and make sure that all children understood the instructions. We computed reading fluency, reading comprehension, and arithmetic skill scores by summing up the z-scores of reading fluency, reading comprehension, and arithmetic skills in Grades 1–3. Cronbach’s alphas for reading fluency score, reading comprehension score, and arithmetic skill score were 0.89, 0.73, and 0.86, respectively.

Reading fluency was assessed using a group-administered subtest of the nationally normed reading achievement test battery ALLU. The test score was the number of correct answers, ranging from 0 to 80, during a 2-minute time limit for items that involved identifying the correct word from four phonologically similar alternatives linked to an adjoining picture.

Reading comprehension was assessed with a group-administered subtest from the ALLU test battery. After reading a short text, children were asked to answer to 12 multiple-choice questions relating to facts, causal relationships, interpretations, or conclusions drawn from the text. The test score was the number of correct answers, ranging from 0 to 12, during the 30-minute test period when children were allowed to refer to the original text.

Arithmetic skills were assessed using a basic arithmetic test with a set of visually presented addition and subtraction tasks. Children were asked to perform as many calculations as they could during the 3-minute time limit. The test score was the number of correct answers, ranging from 0 to 28.

## **Assessment of body size and composition**

Total fat mass, lean mass, and total BF% were measured by a dual-energy X-ray absorptiometry (Lunar®, GE Medical Systems, Madison, WI, USA) at the Department of Clinical Physiology and Nuclear Medicine, Kuopio University Hospital. A trained research nurse conducted the anthropometric measurements at the Institute of Biomedicine, University of Eastern Finland. Body weight was

measured twice after overnight fasting, after emptying the bladder, and standing in light underwear by InBody® 720 bioelectrical impedance device (Biospace, Seoul, Korea) to accuracy of 0.1 kg. The mean of these two values was used for the analyses. Body height was measured three times in the Frankfurt plane without shoes by a wall-mounted stadiometer to accuracy of 0.1 cm. The mean of two nearest values was used in the analyses. Body mass index (BMI) was calculated as body weight divided by body height squared. BMI-standard deviation score (BMI-SDS) was assessed by national references (Saari et al., 2011). The prevalence of normal weight and overweight was defined using the cut-off values provided by Cole et al. (Cole, Bellizzi, Flegal, & Dietz, 2000). Waist circumference was measured after expiration at mid-distance between the bottom of the rib cage and the top of the iliac crest.

### **Assessment of cardiometabolic risk factors**

A trained research nurse took blood samples in the morning after a 12-hour overnight fast (Viitasalo et al., 2012a). Plasma glucose was measured by a hexokinase method, serum insulin by an electrochemiluminescence immunoassay, plasma triglycerides by a colorimetric enzymatic assay and plasma high-density lipoprotein (HDL) cholesterol and plasma LDL cholesterol by homogeneous colorimetric enzymatic assays. A research nurse measured systolic and diastolic blood pressure from the right arm using the Heine Gamma® G7 aneroid sphygmomanometer (Heine Optotechnik, Herrsching, Germany) to accuracy of 2 mmHg. The measurement protocol included a rest of five minutes and thereafter three measurements in the sitting position at 2-minute intervals. The mean of all three values was used as the systolic and diastolic blood pressure. We calculated Homeostatic Model Assessment for Insulin Resistance (HOMA-IR) using the formula  $\text{insulin (mU/L)} \times \text{glucose (mmol/L)} / 22.5$  (Matthews et al., 1985). Continuous MetS score has been suggested to better describe cardiometabolic risk in children than arbitrary cut-offs for MetS (Andersen et al., 2015). We calculated the clustered cardiometabolic risk score by computing population-specific and age-, sex-, and height-standardized z-scores for waist circumference, insulin, glucose, triglycerides, HDL cholesterol, and the



average of systolic and diastolic blood pressure and using the formula waist circumference+insulin+glucose+triglycerides–HDL cholesterol+the average of systolic and diastolic blood pressure, a larger score indicating a higher cardiometabolic risk.

### **Assessments of motor performance, cardiorespiratory fitness, MVPA, and sedentary behaviour**

We used the sum of z-scores for the 50 metre agility shuttle run test time (inverse), errors in the flamingo balance test (inverse), and the number of cubes moved in the box and block test as a measure of motor performance (Haapala et al., 2014). Cardiorespiratory fitness was assessed using maximal cycle ergometer exercise test (Lintu et al., 2014) and was defined as maximal workload divided by DXA derived lean body mass. We used maximal workload per lean body mass because lean body mass is physiologically most appropriate denominator to remove the effect of body size in the fitness measures (Armstrong et al. 2011). Sedentary time and MVPA was objectively assessed using a combined heart rate and movement sensor (Actiheart®, CamNtech Ltd., Papworth, UK) which was attached to the children's chest with two standard ECG electrodes. The children were asked to wear the sensor continuously for a minimum of four days (including sleep and water-based activities) without changing their usual behaviour. The heart rate data were individually calibrated with data from a maximal cycle ergometer exercise test (Collings et al., 2017). We included data on children who had at least 48 h (32 h during weekdays, 16 h during weekend days, represented by  $\geq 12$  h of morning, noon, afternoon, and evening wear time) of valid activity recording in the analyses. We defined sedentary time as activities that were performed below the intensity of 1.5 metabolic equivalents of task (METs) and MVPA as activities exceeding the intensity of 4 METs. Screen-based sedentary behaviour was assessed by a detailed questionnaire (Väistö et al., 2014).

### **Other assessments**

The parents were asked to report their annual household income, that was categorized as  $\leq 30\,000\text{€}$ , 30 001–60 000€ and  $\geq 60\,000\text{€}$  for the analyses. The parents were also asked to report their highest

completed or ongoing educational degrees (e.g. vocational school or less, polytechnic and university) and the degree of the more educated parent was used in the analyses. A research physician assessed pubertal status using the five-stage scale described by Tanner (Tanner, 1962). The boys were defined as having entered clinical puberty, if their testicular volume assessed by an orchidometer was  $>3$  ml (Stage  $\geq 2$ ). The girls were defined having entered clinical puberty if their breast development had started (Stage  $\geq 2$ ).

### **Statistical methods**

We performed all data analyses using SPSS Statistics, Version 23.0 (IBM Corp., Armonk, NY, USA). Basic characteristics between boys and girls were compared using the Student's t-test, the Mann-Whitney U-test, or the Chi Square-test. The associations of BF% and other cardiometabolic risk factors with reading fluency score, reading comprehension score, and arithmetic skill score were studied using linear regression analyses adjusted for age, sex, and parental education. To achieve the largest number of participants with a complete data on variables in the main analyses and therefore to achieve a better statistical power for the analyses on the associations of BF% and other cardiometabolic risk factors with academic achievement, we allowed some missing data in confounding and mediating factors. To replace missing data, we created ten imputed datasets for linear regression analyses (White, Royston, & Wood, 2011). After replacing missing values, all data were further adjusted for motor performance, cardiorespiratory fitness, MVPA, sedentary time, screen-based sedentary behaviour, or household income. We also performed complete-case analyses and the results were materially unchanged.

We tested the mediating effects of abovementioned factors on the associations of BF% and other cardiometabolic risk factors with academic achievement using the regression approach presented by Baron and Kenny (Baron & Kenny, 1986). To test mediation with this approach three regression steps are required: 1) the independent variable must be related to dependent variable and mediator, 2) mediator must be associated with dependent variable, and 3) the association between independent and

dependent variable must weaken when mediator is adjusted for in the model. We performed mediation analyses for variables that were found to attenuate the associations of BF% and other cardiometabolic risk factors with academic achievement scores in the linear regression analyses.

## RESULTS

### Characteristics of the children

Boys were older and taller, were more physically active, and had higher cardiorespiratory fitness than girls (Table 1). Boys also had a lower BF%, HOMA-IR, serum leptin concentration, and reading fluency and reading comprehension scores than girls.

### Associations of adiposity with academic achievement

In all children, BF% was not associated with academic achievement ( $\beta = -0.100$ ,  $P = 0.215$  for reading fluency score,  $\beta = -0.141$ ,  $P = 0.069$  for reading comprehension score,  $\beta = -0.007$ ,  $P = 0.937$ ). However, sex modified the associations of BF% with reading fluency score ( $P$  for interaction = 0.006) and arithmetic skill score ( $P$  for interaction = 0.015).

In boys, BF% was inversely associated with reading fluency and reading comprehension scores after adjustment for age and parental education (Table 2). The association between BF% and reading fluency score was no longer statistically significant after further adjustment for motor performance ( $\beta = -0.163$ , 95% CI = -0.348 to 0.022,  $P = 0.084$ ). The relationship of BF% to reading comprehension score was not statistically significant after further adjustment for motor performance ( $\beta = -0.102$ , 95% CI = -0.269 to 0.092,  $P = 0.303$ ) or MVPA ( $\beta = -0.176$ , 95% CI = -0.398 to 0.046,  $P = 0.121$ ). Further adjustment for cardiorespiratory fitness, sedentary time, screen-based sedentary behaviour, or household income had no effect on these associations (data not shown).

In girls, BF% was not associated with academic achievement after adjustment for age and parental education (Table 2).

## Associations of other cardiometabolic risk factors with academic achievement

In all children, the clustered cardiometabolic risk score, HOMA-IR, or ALAT were not associated with academic achievement after adjustment for age, sex, and parental education. GGT was inversely associated with reading fluency score after adjustment for age, sex, and parental education ( $\beta=-0.152$ , 95%=-0.300 to -0.005,  $P=0.043$ ). However, the relationship was no longer statistically significant after further adjustment for BF% ( $\beta=-0.134$ , 95%=-0.291 to 0.023,  $P=0.093$ ), motor performance ( $\beta=-0.115$ , 95%=-0.258 to 0.028,  $P=0.115$ ), and MVPA ( $\beta=-0.142$ , 95%=-0.290 to 0.006,  $P=0.060$ ).

Among boys, serum leptin concentration was inversely associated with reading fluency and reading comprehension scores after adjustment for age and parental education (Table 2). The inverse associations of serum leptin with reading fluency score was no longer statistically significant after further adjustment for motor performance ( $\beta=-0.166$ , 95%=-0.363 to 0.031,  $P=0.098$ ). Further adjustment for BF%, cardiorespiratory fitness, sedentary time, screen-based sedentary behaviour, or household income had no effect on these associations (data not shown).

Among girls, GGT was inversely associated with reading fluency score after adjustment for age and parental education. Further adjustments had no effect on these associations.

## Mediation analyses

Because sex modified the associations of BF% with academic achievement, we performed mediation analyses separately for boys and girls. The mediation effect of motor performance on the associations of BF% with academic achievement among boys are illustrated in Figure 1. In boys, as demonstrated in the main analyses, BF% was inversely associated with academic achievement (pathway 1). BF% was also inversely associated with motor performance ( $\beta = -0.313$ , 95% CI = -0.527 to -0.099,  $P=0.004$ ) (pathway 2) and motor performance was directly related to reading fluency ( $\beta=0.403$ , 95%=-0.207 to 0.598,  $P<0.001$ ) and reading comprehension ( $\beta=0.350$ , 95% CI = 0.145 to 0.554,  $P=0.001$ ) scores (pathway 3) after adjustment for age and parental education. The associations of BF% with reading

fluency and reading comprehension scores were not statistically significant after adjustment for motor performance (pathway 4). The relationships of motor performance to reading fluency and reading comprehension scores were independent of BF% ( $P \leq 0.001$ ). Furthermore, BF% was inversely associated with MVPA ( $\beta = -0.462$ , 95% CI = -0.644 to -0.279,  $P < 0.001$ , pathway 2) but MVPA was not associated with reading comprehension score ( $\beta = 0.118$ , 95% CI = -0.079 to 0.316,  $P = 0.240$ , pathway 3). Further analyses showed that motor performance mediated the association of leptin and reading fluency score in boys (data not shown). In girls, we found no evidence on mediation.

## DISCUSSION

We found that a higher BF% was associated with poorer reading fluency and reading comprehension scores in boys. However, these associations were largely explained by differences in motor performance between boys with lower and higher BF%. Leptin was inversely associated with reading fluency and reading comprehension scores in boys, but motor performance also mediated the association of plasma leptin and reading fluency score. Furthermore, GGT was inversely associated with reading comprehension in girls independent of confounding factors. Finally, cardiorespiratory fitness, MVPA, or sedentary behaviour had weak if any effect on observed associations.

Increased adiposity has been associated with poorer cognitive functions and academic achievement in children and adolescents (Davis & Cooper, 2011; Kamijo, Khan, et al., 2012; Kavanagh et al., 2011; Reinert et al., 2013). We found that a higher BF% assessed by DXA was associated with poorer reading skills only in boys. Few studies have stratified their analyses by sex, but our findings are in contrast to some studies suggesting a stronger inverse association of overweight and obesity with academic achievement in girls than in boys (Booth et al., 2014; Datar & Sturm, 2006). However, overweight and obesity at the age of three have been inversely associated with cognition at the age of five in boys but not in girls (Martin et al. 2015). Differences in methods used to assess adiposity,

sociocultural differences between countries, or maturation and school-readiness may modify the associations between adiposity and academic achievement and thus explain these partially contrasting findings. Our observation of the mediating effect of motor performance on the associations of adiposity and other cardiometabolic risk factors with academic achievement among boys may also explain these sex-specific findings.

Motor performance mediated the inverse associations of BF% with reading skills in boys suggesting that boys with a poorer motor performance also had a higher BF% and worse reading skills. We have previously found strong direct associations of motor performance with academic achievement and cognition in boys but not in girls (Haapala et al., 2015; Haapala et al., 2014). Furthermore, we have found that motor performance partially explained the differences in cognition between boys with moderate and high BF% (Haapala et al., 2015). Previous studies have provided some evidence that the associations of cardiorespiratory fitness and motor performance with cognition and academic achievement are stronger in boys than in girls (Drollette et al., 2015; Jaakkola, Hillman, Kalaja, & Liukkonen, 2015). Explanation for these sex-dimorphic findings may be that better motor skills may improve school adjustment, social networks, and self-esteem especially in boys leading to better academic achievement (Sawka, McCormack, Nettel-Aguirre, Hawe, & Doyle-Baker, 2013). Sex differences in brain structure, function, and chemistry may also explain these sex-specific associations (Cosgrove, Mazure, & Staley, 2007). Furthermore, boys' brains may be more vulnerable to environmental factors, such as increased adiposity, than that of girls (Isaacs et al. 2008). These results together suggest that motor performance may be more important for academic achievement than adiposity in boys and therefore emphasize motor skill training during early and mid-childhood (Haapala, 2013; Koutsandreu, Wegner, Niemann, & Budde, 2016; Robinson et al., 2015). Reasons for these observations on the mediating effects of motor performance are complicated and multifaceted, but may include low levels of physical activity during early childhood that have led to increased

adiposity, poor motor performance, and suboptimal development of brain and thereby poor academic achievement (Donnelly et al., 2016; Robinson et al., 2015).

In contrast to some studies (Yates et al., 2012), cardiometabolic risk factors such as the clustered cardiometabolic risk score or HOMA-IR were not associated with academic achievement in our study. One reason for this finding may be that children in our study were relatively young and healthy. It is possible that to cause significant impairments on brain health and cognition, a longer exposure to elevated cardiometabolic risk factors in childhood is required (Yates et al., 2012).

We found inverse associations of leptin concentration with reading fluency and reading comprehension in boys. These results are in line with one previous study suggesting that increased plasma leptin levels are linked to poorer academic achievement in adolescents (Correa-Burrows et al., 2016). Chronically increased leptin concentrations may cause leptin resistance and reduced hippocampal synaptic plasticity leading to impaired learning and academic performance (Voss, Carr, Clark, & Weng, 2014). Furthermore, motor performance mediated the association of leptin and reading fluency and therefore the independent associations of leptin with academic achievement should be interpreted with caution.

To the best of our knowledge, this is the first study on the associations of non-alcoholic fatty liver disease-related liver enzymes with academic achievement in children. We found an inverse association of GGT with reading fluency in girls but not in boys. GGT has been found to be a valid indicator of hepatic intracellular fat accumulation, hepatic cell inflammation, and non-alcoholic fatty liver disease (Mason, Starke, & Van Kirk, 2010). The inverse association of GGT with reading fluency may be due to increased systemic inflammation or oxidative stress but increased GGT may also reflect more generic metabolic dysfunction, which may have negative effects on the brain (Mason et al., 2010). Furthermore, higher GGT has been linked to increased risk of Alzheimer's disease in middle-aged and older adults independent of other cardiometabolic risk factors (Kunutsor & Laukkanen, 2016). ALT was not associated with academic achievement in the present study. One reason for this observation

may that in our study population GGT had stronger association with MetS and systemic inflammation than ALT (Viitasalo et al., 2012a). These results together suggest that high normal GGT concentrations may have negative effects on the brain and learning, but specific mechanisms and reasons for our sex-dimorphic observation are currently unknown. Furthermore, because we found an association of GGT only with reading fluency and only in girls, these results and their practical significance must be interpreted with caution.

MVPA did not mediate the associations of BF% and cardiometabolic risk factors with academic achievement. Previous studies suggest that physical activity has positive effects on cognition and academic achievement in overweight and obese children (Davis et al. 2011; Hillman et al. 2014). These studies have also demonstrated reduced adiposity in response to exercise intervention (Davis et al. 2011; Hillman et al. 2014). A recent study found that improvements in cognitive functions after physical activity intervention were related to decreases in adiposity in children (Raine et al. 2017). Therefore, physical activity may modify the association of adiposity with cognition and academic achievement in children. However, physical activity may also have adiposity-independent effects on academic achievement. It is probable that physical activity and adiposity influence on academic achievement by different pathways (Donnelly et al. 2016; Haapala et al. 2017). We also found that sedentary behaviour or cardiorespiratory fitness did not mediate these associations. One reason for these observations may be that cardiorespiratory fitness expressed as maximal workload per lean body mass is not confounded by adiposity (Armstrong et al. 2011) and therefore cardiorespiratory fitness is not expected to have a major effect on the association of adiposity with academic achievement. An explanation why sedentary behaviour had no effect on the associations of adiposity and other cardiometabolic risk factors with academic achievement may be that sedentary behaviours may not be causally linked to adiposity (Biddle et al. 2017) and that the associations of different sedentary behaviours with academic achievement may be either inverse or direct (Haapala et al. 2014a).



The strengths of the present study are the rigorous methods used to assess adiposity, cardiometabolic risk factors, and academic achievement. The main limitation of the study is that we only used the cross-sectional measures of adiposity and cardiometabolic risk factors that precludes causal interpretation. We also allowed some missing data on confounding factors to achieve a maximal sample size in our primary analyses. Imputed data may reduce variability and therefore partially mask the true magnitude of the mediation effects. However, the results were similar in the complete case analyses. Furthermore, the MET-based cut-offs used to define objectively measured sedentary behaviour and MVPA may under or overestimate the time spent in these movement behaviours.

In conclusion, we found that a higher BF% and serum leptin concentration were related to poorer reading skills in boys aged 6–8 years. However, these associations were largely mediated by motor performance. In girls, GGT, but not adiposity or other cardiometabolic risk factors, was inversely associated with reading fluency score. Further studies to investigate the longitudinal trajectories of adiposity and other cardiometabolic risk factors to academic achievement are warranted. Finally, further studies are needed to more comprehensively understand possible negative effects of elevated leptin and high normal levels of GGT on brain, cognition, and academic achievement in children.

### **Disclosure of interest**

The authors report no conflicts of interest

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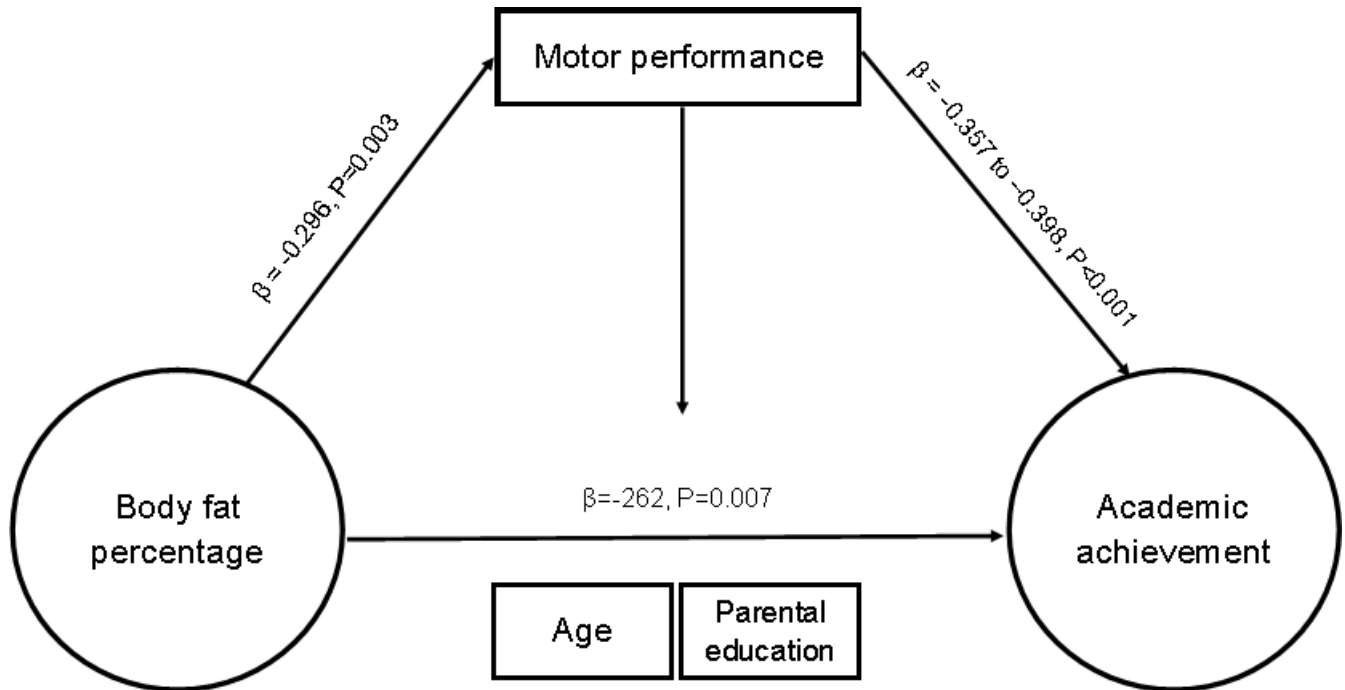


Figure 1. The mediation effect of motor performance on the association of body fat percentage with academic achievement in boys. \*\* $P < 0.01$ ; \*\*\* $P = 0.001$ ; NS = non-significant



Table 1. Basic characteristics

	All	Boys	Girls	<i>P</i>
<b>Background characteristics</b>				
Age (years)	7.7 (0.4)	7.7 (0.4)	7.6 (0.3)	0.034
Pubertal (%)	2.9	2.9	3.0	0.648
Parental education (%)				0.144
Vocational school or less	19.7	22.9	14.7	
Polytechnic	39.9	34.3	48.5	
University degree	40.5	42.9	36.8	
Household income (%)				0.419
≤30,000	20.5	22.3	17.6	
30,001–60,000	46.8	42.7	52.9	
>60,000	32.7	35.0	29.4	
Moderate-to-vigorous physical activity (min/d) <sup>1</sup>	102 (69.5)	104 (75.8)	82.4 (59.5)	<0.001
Sedentary time (min/d) <sup>1</sup>	262 (170)	250 (179)	262 (158)	0.384
Habitual screen-based sedentary behaviour (min/d) <sup>1</sup>	101 (66.4)	103 (69.1)	98.6 (48.8)	0.088
Maximal work load / lean body mass (W/kg)	3.6 (0.5)	3.7 (0.5)	3.4 (0.4)	<0.001
Motor performance z-score <sup>1</sup>	0.3 (2.7)	0.2 (2.8)	0.5 (2.7)	0.769
<b>Body size and composition</b>				
Body height (cm)	129 (5.7)	130 (5.9)	128 (5.2)	0.022
Body weight (kg) <sup>1</sup>	26.1 (5.8)	26.6 (5.7)	25.6 (6.2)	0.142
Body mass index – standard deviation score	-0.2 (1.1)	-0.1 (1.1)	-0.2 (1.1)	0.820
Prevalence of overweight and obesity (%)	14.9	14.2	15.9	0.745
Body fat percentage <sup>1</sup>	18.3 (11.2)	14.9 (11.0)	20.7 (34.0)	<0.001
<b>Cardiometabolic risk factors</b>				
Clustered cardiometabolic risk score	-0.10 (3.7)	-0.32 (3.8)	0.24 (3.6)	0.336
Homeostatic model to assess insulin resistance <sup>1</sup>	0.9 (0.8)	0.9 (0.8)	1.1 (0.6)	0.027
Serum leptin (ng/ml) <sup>1</sup>	3.7 (3.1)	3.2 (2.3)	4.4 (5.2)	<0.001
Plasma alanineaminotransferase (μ/L) <sup>1</sup>	18.0 (6.0)	18.0 (6.0)	18.0 (6.0)	0.807
Plasma glutamyltransferase (μ/L) <sup>1</sup>	12.0 (3.0)	12.0 (3.0)	12.0 (3.0)	0.296
<b>Academic achievement</b>				
Reading fluency score (0–340)	80.7 (23.3)	78.1 (26.0)	84.8 (17.9)	0.044
Reading comprehension score (0–36)	21.6 (6.9)	20.6 (7.5)	23.2 (5.5)	0.010
Arithmetic skills score (0–84)	45.5 (12.0)	45.3 (13.0)	45.9 (10.2)	0.713

The data are mean (standard deviations), median (interquartile range<sup>1</sup>), or percentages and the *P*-values from the *t*-test for independent samples for continuous variables with normal distribution and Mann-Whitney U-test for continuous variables with skewed distribution, or Chi-square for categorical variables.

Table 2. Associations of body fat percentage and other cardiometabolic risk factors with reading and arithmetic skills scores in 6–8-year-old children

	Reading fluency				Reading comprehension				Arithmetic skills			
	Boys		Girls		Boys		Girls		Boys		Girls	
	$\beta$ (95% CI)	<i>P</i>	$\beta$ (95% CI)	<i>P</i>	$\beta$ (95% CI)	<i>P</i>	$\beta$ (95% CI)	<i>P</i>	$\beta$ (95% CI)	<i>P</i>	$\beta$ (95% CI)	<i>P</i>
Body fat percentage	-0.262 (-0.451; -0.074)	<b>0.007</b>	0.080 (-0.164; 0.325)	0.515	-0.216 (-0.405; -0.027)	<b>0.025</b>	0.001 (-0.226; 0.229)	0.992	-0.148 (-0.342; 0.046)	0.133	0.195 (-0.053; 0.442)	0.122
Clustered cardiometabolic risk score	-0.038 (-0.236; 0.161)	0.708	-0.028 (-0.287; 0.231)	0.828	-0.005 (-0.201; 0.192)	0.961	-0.171 (-0.407; 0.065)	0.152	-0.066 (-0.266; 0.135)	0.517	0.052 (-0.214; 0.318)	0.696
HOMA-IR	-0.059 (-0.257; 0.139)	0.555	-0.037 (-0.276; 0.202)	0.757	-0.019 (-0.215; 0.177)	0.845	-0.208 (-0.423; 0.007)	0.058	-0.043 (-0.243; 0.157)	0.670	0.004 (-0.242; 0.249)	0.976
GGT	-0.093 (-0.291; 0.104)	0.350	-0.325 (-0.556; -0.093)	<b>0.007</b>	-0.042 (-0.238; 0.154)	0.674	-0.067 (-0.293; 0.158)	0.553	-0.028 (-0.228; 0.172)	0.782	-0.232 (-0.477; 0.012)	0.062
ALAT	-0.050 (-0.247; 0.247)	0.616	0.136 (-0.100; 0.371)	0.255	-0.168 (-0.360; 0.024)	0.085	0.084 (-0.135; 0.303)	0.447	0.027 (-0.172; 0.226)	0.788	0.059 (-0.185; 0.303)	0.630
Leptin	-0.272 (-0.464; -0.080)	<b>0.006</b>	-0.027 (-0.270; 0.217)	0.827	-0.287 (-0.476; -0.098)	<b>0.003</b>	-0.035 (-0.260; 0.190)	0.754	-0.188 (-0.387; 0.010)	0.062	0.143 (-0.105; 0.391)	0.253

Data are standardized regression coefficient ( $\beta$ ) and their 95% confidence intervals (95% CI) adjusted for age and parental education. MetS=metabolic syndrome, HOMA-IR=Homeostatic Model to Assess Insulin Resistance, ALAT=Plasma alanineaminotransferase, GGT=Plasma glutamyltransferase