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Title: Motor competence and cardiorespiratory fitness have greater influence on body fatness than physical activity across time

Running head: Body fatness causal factors during childhood

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Abstract

**Aim:** We investigated the longitudinal associations among physical activity (PA), motor competence (MC), cardiorespiratory fitness (VO$_2$peak) and body fatness across seven years, and also analyzed the possible mediation effects of PA, MC and VO$_2$peak on the relationships with body fatness. **Materials and methods:** This was a seven-year longitudinal study with three measuring points (mean ages [in years] and respective sample size: 6.75 ±0.37, n=696; 9.59 ±1.07, n=617; 13.35 ±0.34, n=513). PA (moderate-to-vigorous PA – MVPA and vigorous PA – VPA) was monitored using accelerometers. MC was assessed by the ‘Körperkoordinationstest für Kinder – KTK’ test battery. VO$_2$peak was evaluated using a continuous running protocol until exhaustion. Body fatness was determined by the sum of four skinfolds. Structural equation modeling was performed to evaluate the longitudinal associations among PA, MC, VO$_2$peak and body fatness and the potential mediation effects of PA, MC and VO$_2$peak. All coefficients presented were standardized (z-scores). **Results:** MC and VO$_2$peak directly influenced the development of body fatness, and VO$_2$peak mediated the associations between MVPA, VPA, MC and body fatness. MC also mediated the associations between MVPA, VPA and body fatness. In addition, VO$_2$peak had the largest total association with body fatness ($\beta$= -0.431; p<0.05), followed by MC ($\beta$= -0.369; p<0.05) and VPA ($\beta$= -0.112; p<0.05). **Conclusion:** Since PA, MC and VO$_2$peak exhibited longitudinal association with body fatness, it seems logical that interventions should strive to promote the development of fitness and MC through developmentally appropriate physical activities, as the synergistic interactions of all three variables impacted body fatness.

**Keywords:** Obesity, children, health behaviors, longitudinal studies, motor activity, physical fitness
Introduction

The worldwide increase in childhood obesity prevalence has attracted the attention of public health professionals. Obesity is one of the major causes of morbidity and mortality (Haslam & James 2005; Rodgers et al. 2004) and is associated with increasing medical expenditures (Spieker & Pyzocha 2016). Additionally, obese children are more likely to be obese adults (Bass & Eneli 2015), and obesity is linked to several health issues (e.g. type 2 diabetes, cardiovascular diseases and various types of cancer) (Bass & Eneli 2015). While a wealth of research has been conducted to provide better understanding about causal factors related to childhood obesity, (Hendrix et al. 2014; Pate et al. 2013) alleviating this growing problem has been limited (Sahoo et al. 2015); thus, examining factors related to obesity requires further investigation.

Stodden et al. (2008) published a conceptual framework that hypothesizes how physical activity, motor competence and health-related fitness could longitudinally influence obesity risk. According to the framework, physical activity, motor competence and health-related fitness are suggested to demonstrate reciprocal longitudinal relationships with strengths of associations increasing across childhood and into adolescence. The framework also indicates that health-related fitness mediates the relationship between physical activity, motor competence and obesity risk. Substantial research has been published evaluating the longitudinal impact of physical activity, motor competence and fitness on body fatness (Hendrix et al. 2014; Pate et al. 2013) and the mediation role of physical fitness (Khodaverdi et al. 2016). However, most studies investigated the relationships individually, not taking into account how those components interact and predict later body fatness in children and adolescents (Robinson et al. 2015).

There is strong evidence linking motor competence to physical activity (Cairney & Veldhuizen 2013; Robinson et al. 2015), fitness (Cairney & Veldhuizen 2013; Cattuzzo et al. 2014) and weight status (Cairney & Veldhuizen 2013; Cattuzzo et al. 2014; Robinson et al. 2015), both in childhood and adolescence. Cairney and Veldhuizen (2013) analyzed the literature to evaluate if motor coordination disorder could cause physical inactivity, poor physical fitness and body fatness, using Hill’s causal criteria (Bradford-Hill 1965). Motor competence fulfilled four out of nine criteria of causality regarding physical activity (biological plausibility, coherence, consistency and strength of association) (Cairney & Veldhuizen 2013). According to the Cairney and Veldhuizen (2013) evaluation, the major factors in favor of the causal relationship between poor motor competence and inactivity are the biological

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and behavioral plausibility and coherence, especially as developed by the conceptual models of Stodden et al. (2008) and Hands and Larkin (2002). Both frameworks suggest that children with poor motor competence find it difficult and unpleasant to participate in activities for which motor competence is required, which in turn influences PA level, fitness and body fatness. Reciprocally, increased body fatness and low fitness hinders participation in PA and decreases the likelihood that individuals will develop motor competence.

Likewise, the logical influence that the development of motor competence has on fitness levels has strong empirical support (Hands & Larkin 2002; Stodden et al. 2008). Despite the fact that motor competence has been linked to three different components of health-related fitness (aerobic capacity, anaerobic capacity, and strength), only aerobic fitness has been investigated in longitudinal studies. Overall, the strength of the association between motor competence and fitness variables varied widely across the three components of fitness, but it was stronger for the influence on aerobic fitness (Cairney & Veldhuizen 2013). Cairney and Veldhuizen (2013) characterized the evidence of a causal relationship between motor competence and fitness as relatively strong. Additionally, Ortega et al. (2013) systematically reviewed evidence of the longitudinal association between physical fitness and obesity. According to the review, high physical fitness level in childhood and adolescence is inversely associated to current and future adiposity levels.

Similarly, motor competence fulfilled six out of nine Hill’s criteria for causality in relation to body fatness (biological plausibility, coherence, consistency, experimentation, dose-response and strength of association) in Cairney and Veldhuizen (2013). The influence of motor competence on body fatness has been investigated across several studies, with different age ranges, different methods and techniques to measure body fatness (Cairney et al. 2011). In addition, the influence of motor competence on body fatness has biological and behavioral plausibility and coherence (Hands & Larkin 2002; Stodden et al. 2008). Researchers have also acknowledged the increase in the strength of associations between motor competence and body fatness in both cross-sectional and longitudinal studies. Specifically, poor motor coordinated children have a much higher risk of becoming overweight/obese (Cairney et al. 2011; D’Hondt et al. 2013; D’Hondt et al. 2011; Lopes et al. 2012; Rodrigues et al. 2016).

Higher physical activity and physical fitness levels have been longitudinally associated with lower body fatness levels in children and adolescents. Ortega et al. (2013) summarized the evidence on the relationships between physical activity, physical fitness and body fatness. The authors observed that high levels of physical activity and physical fitness are inversely associated with body fatness, while low levels of physical activity and physical fitness are positively associated with body fatness.

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activity and physical fitness (especially aerobic fitness) during childhood and adolescence were associated with lower body fatness during childhood and adolescence. Moore et al. (2003) followed preschool children for eight years and observed that children in the highest physical activity tertile during the follow-up had smaller gains in BMI, and body fatness (sum of five skinfolds) throughout childhood. Pate et al. (2013) summarized the evidence that evaluated the prospective association between objectively measured physical activity and body fatness. From the seven studies evaluated, six observed that higher physical activity level was related to a decrease in body fatness, with only one study finding no association.

Overall, evidence demonstrating longitudinal associations among physical activity, physical fitness, and body fatness (assessed simultaneously) is scarce. A systematic review (Rauner et al. 2013) found only two longitudinal studies that investigated associations among physical activity, physical fitness and body fatness (Aires et al. 2010; He et al. 2011). To the best of our knowledge, only Martins et al. (2010) and Lopes et al. (2012) have investigated how physical activity, motor competence and physical fitness were longitudinally associated with body fatness. Lopes et al. (2012) observed both motor competence and physical fitness were associated with body fatness (sum of two skinfolds). Martins et al. (2010) demonstrated that, among motor competence, physical activity and fitness, only motor competence was negatively associated with BMI across three years. However, the authors used indirect measures of physical activity and were limited to a three-year follow-up in childhood. Neither of the two aforementioned studies addressed potential mediation pathways among those factors included in the conceptual framework (Stodden et al. 2008). Therefore, long-term longitudinal studies analyzing the combined impact of objectively measured physical activity, motor competence and physical fitness on body fatness across childhood and adolescence are needed (Rauner et al. 2013). Thus, the aims of this study were to: 1) investigate the longitudinal associations among physical activity (i.e., moderate-to-vigorous physical activity and vigorous physical activity), motor competence, cardiorespiratory fitness and body fatness across seven years; and 2) understand the extent to which VO_{2peak}, physical activity and motor competence each would be potential mediators within the combination of these variables to predict body fatness.

We hypothesized that physical activity, motor competence and cardiorespiratory fitness would be longitudinally associated with body fatness and that cardiorespiratory fitness, physical activity and motor competence would mediate the other relationships with body fatness.
Materials and methods

This study was based on longitudinal data from the “Copenhagen School Child Intervention Study”, which began in 2001. Children attending preschool class in two communities in the area of Copenhagen (46 preschool classes in 18 schools [mean age = 6.75 ±0.37]) were recruited to participate in the study. Written informed consent was obtained from the parents/guardians of 706 children (69% of the sample), and 696 actually participated in the study at baseline. The original intervention consisted of four components: a) an increase in the amount of physical education (PE) lessons from 90 to 180 min/week; b) lessons in health education, focusing on the importance of physical activity and healthy eating; c) three to four full days a year of supplementary training for the PE teachers that focused on didactic tools to enhance the children’s motivation for and enjoyment of physical activity and, at the same time, keeping the intensity in PE lessons moderate-to-vigorous; d) upgrades to indoor and outdoor PE and playing facilities in all intervention schools (Bugge et al. 2012). Following the intervention, which lasted three years, the children were retested at nine years-of-age (mean age = 9.59 ±1.07) and followed up again in 2008 at 13 years (mean age = 13.35 ±0.34). The study was approved by the ethical committee, University of Copenhagen.

Because the complete methodology has been previously published (Bugge et al. 2012; Eiberg et al. 2005; Hasselstrom et al. 2008), the methodology here presents only those variables of interest. Pubertal status was assessed by self-report of sexual maturation using a scale of pictures of breast development for girls and genital development for boys. Numbers were rated 1-5, according to criteria described by Tanner (1986). Biceps, triceps, subscapular, and suprailiac skinfolds were measured on the self-reported non-dominant side of the body by the same two skilled researchers with a Harpenden skinfold caliper (Harpender, West Sussex, UK), and the body fatness was computed as the sum of the four skinfolds (S4SF).

Cardiorespiratory fitness (VO\textsubscript{2peak}) was assessed in ml/(kg·min) using a continuous running protocol on a treadmill until exhaustion. VO\textsubscript{2peak} was measured directly on an AMIS 2001 Cardiopulmonary Function Test System (Innovision, Odense, Denmark) at ages six and nine years-of-age, and using a COSMED K4b\textsuperscript{2} portable metabolic system (COSMED, Rome, Italy) at 13 years-of-age. Both systems provide valid measure of VO\textsubscript{2} when validated against the Douglas bag method (Eiberg et al. 2005; Jensen et al. 2002; McLaughlin et al. 2001). We tested whether VO\textsubscript{2peak} scaled in ml/min or in ml/height/min would change the interpretation of the results because of the weight component included in the VO\textsubscript{2peak} unit of measurement in ml/(kg·min). However, no significant difference in the

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association between VO_{2peak} and body fatness was observed regardless of the VO_{2peak} unit. Thus, we used VO_{2peak} in ml/(kg·min) in our analyses.

In this study, the term motor competence is defined as “the degree of skilled performance in a wide range of motor tasks as well as the movement coordination and control underlying a particular motor outcome” (D’Hondt et al. 2009). Motor competence was assessed using the “Körperkoordinationstest für Kinder” (KTK), which is a standardized, normative, German test battery (Kiphard & Schilling 1974; Kiphard & Schilling 2007). The KTK has high test-retest reliability (0.90 to 0.97) (Kiphard & Schilling 1974; Kiphard & Schilling 2007). The KTK consists of four independent tests: (1) walking backwards on balance beams of decreasing width: 6.0, 4.5, and 3.0 cm, (2) moving sideways on wooden boards for 20s, (3) one-legged hopping over a foam obstacle with increasing height in consecutive steps of 5cm and (4) two-legged jumping from side to side for 15s. The KTK battery test was originally developed to identify children with motor disorders and behavioral disorders; however, the KTK battery has been used in numerous studies to evaluate motor competence performance levels in normally developing children and adolescents up to 15 years-of-age (D’Hondt et al. 2013; Graf et al. 2004; Laukkanen et al. 2014; Morrison et al. 2012). In our study, motor competence is the sum of the four KTK tests for each age of measurement (six, nine and 13 years of age).

Physical activity was measured using Actigraph 7164 accelerometer (ActiGraph LLC, Pensacola, FL) at baseline and Actigraph GT1M at the two follow-ups in epochs of 10 seconds. All the devices were calibrated in a motor driven vertical acceleration machine before use. The participants wore an elastic belt with the accelerometer on the right side of the waist, close to the center of gravity. The device was only supposed to be removed while sleeping and during activities involving water. Periods with 30 or more minutes with consecutives zeros counts were considered as non-wear periods. A valid day was noted at a minimum of 10 hours of wear time. Children with four or more valid days were included in the analyses. To calculate the minutes spent in moderate-to-vigorous physical activity (MVPA) and vigorous physical activity (VIG PA) we used Evenson’s cut-points (Evenson et al. 2008) because of its valid estimation for the age range of the participants in the present study (Trost et al. 2011) – Sedentary ≤ 100 counts per minute (cpm); Light >100cpm; Moderate ≥ 2296cpm; Vigorous ≥ 4012cpm (Evenson et al. 2008). We created the variable ‘valid PA weekend days’ (yes and no) to adjust the analyses because we did not require one of the four valid accelerometer days to be a weekend day.

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Statistical analysis

In all analyses, we used STATA version 14.0 (StataCorp LP, College Station, TX, USA). We based our analysis in the conceptual framework first proposed by Stodden et al. (2008) in which physical activity, motor competence and physical fitness all interact synergistically and influence the development of body fatness across time. Therefore, we used structural equation modeling (SEM) to analyze: i) if physical activity, motor competence and VO_{2peak} longitudinally influence body fatness; ii) the possible mediation effects of VO_{2peak}, physical activity and motor competence on their relationships with body fatness. The results were presented in three different components: Direct association – straight association coefficient between two variables; Indirect association – association between two variables that is mediated by a third variable, and; total association – the sum of the direct and indirect association between variables.

Figure 1 presents the pathways examined in the analysis. In summary, we tested if all variables influenced physical activity, motor competence, VO_{2peak} and body fatness. We also examined if physical activity, motor competence and VO_{2peak} influenced body fatness, and if ‘Valid PA weekend days’ influenced physical activity level in our model. Sex, valid PA weekend days (valid PA weekend day monitored – yes and no), pubertal status (pre-pubertal and pubertal), follow-ups (age at the measurements – six, nine and 13 years of age) and intervention (enrolled in the intervention schools – yes and no) were controlled in all the analyses. In addition, physical activity and motor competence were examined with VO_{2peak} as a mediating variable leading to body fatness (dotted arrows). Complementarily, motor competence was also evaluated as a mediating component on the relationship between physical activity and body fatness, whereas physical activity was evaluated as a mediating component on the relationship between motor competence and body fatness. Independent of the physical activity outcome used (vigorous or moderate-to-vigorous physical activity), the model adequately fit the data: CFI = 0.99, TLI = 0.98, RMSEA = 0.02, SRMR = 0.01 (Hoyle 1995). Note that all follow-up measures were included as one box (“follow-ups”) in Figure 1 because it is difficult to show the complexity of all variables assessed at all time points within one figure. Thus, Figure 2 shows a simplified version of how longitudinal relationships were assessed, and it does not include the covariates or show potential mediation paths. It specifically depicts the mathematical calculation of the longitudinal association between MVPA and body fatness (S4SF) taking into consideration the three data collection time points. Importantly, this example applies to the calculation of the coefficients between any variables in our
model. In this example, to present the overall association between MVPA and body fatness, SEM calculated the association between MVPA at six years of age and body fatness at six years of age. At the same time, the association between MVPA at six years of age and body fatness at nine years of age was calculated, taking into account the body fatness at six years of age (dotted arrow from body fatness at six years of age to body fatness at nine years of age). Additionally, the association between MVPA at nine years of age and body fatness at nine years of age was calculated, taking into account both MVPA (dotted arrow from MVPA at six years of age to MVPA at nine years of age) and body fatness at six years of age (dotted arrow from body fatness at six years of age to body fatness at nine years of age). The same calculation was performed between MVPA at six and nine years of age and body fatness at 13 years of age (see Figure 2). Any of the coefficients on the longitudinal association between two variables presented in the results section are an aggregate coefficient based on the calculations described previously. The associations coefficients presented in the results section were standardized to directly compare different variables and their association between them in standard deviation (SD).

In order to take into account the fact that data were clustered by school and classes within school, we completed a separate analysis to calculate the variance related to the clusters of nested data and the intraclass correlation coefficient (ICC) for each model to interpret the variation between school classes, classes, and individuals (Goldstein et al. 2002; Merlo et al. 2006). In all the models, the majority of the variation (ICC) was based on the individual level; the ICCs from school and classes were always below 5%. Because the STATA software does not concomitantly calculate the ICC in each nesting structure and the post-estimation model fit parameters using SEM, we decided to not adjust the model for the nesting structure in order to evaluate whether the proposed model adequately fitted the data. In other words, given the limitations of STATA and the fact that the ICC among schools and classes barely contributed variance to the model, we felt it was more important to be able to estimate model fit parameters instead of accounting for the clustering effect.

**Results**

Boys spent more time in MVPA and VPA and exhibited higher VO$_{2}$peak than girls at each time point. Girls presented higher body fatness than boys at each time point. No differences between boys and girls were observed in the KTK scores at any age (see Table 1).

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MVPA was not directly associated with body fatness ($\beta_{\text{MVPA}} = 0.044 \text{ SD}; 95\% \text{ CI: -0.017: 0.105}$). However, MVPA was associated with body fatness via motor competence ($\beta_{\text{MVPA}} = -0.033 \text{ SD}; 95\% \text{ CI: -0.053: -0.013}$) and fitness ($\beta_{\text{MVPA}} = -0.060 \text{ SD}; 95\% \text{ CI: -0.092: -0.029}$) as mediators. The total association between MVPA and body fatness was not significant ($\beta_{\text{MVPA}} = -0.049 \text{ SD}; 95\% \text{ CI: -0.118: 0.020}$). Motor competence was directly associated with body fatness ($\beta_{\text{MC}} = -0.230 \text{ SD}; 95\% \text{ CI: -0.287: -0.173}$). In addition, the association between motor competence and body fatness was mediated only via fitness ($\beta_{\text{MC}} = -0.147 \text{ SD}; 95\% \text{ CI: -0.181: -0.113}$), not via MVPA ($\beta_{\text{MC}} = 0.005 \text{ SD}; 95\% \text{ CI: -0.002: 0.012}$). Motor competence also presented a total association with body fatness ($\beta_{\text{MC}} = -0.337 \text{ SD}; 95\% \text{ CI: -0.437: -0.318}$). Finally, fitness was associated with body fatness directly ($\beta_{\text{FIT}} = -0.229 \text{ SD}; 95\% \text{ CI: -0.497: -0.376}$) (see Figure 3).

Similar to MVPA, VPA was not directly associated with body fatness ($\beta_{\text{VPA}} = 0.004 \text{ SD}; 95\% \text{ CI: -0.057: 0.065}$), but VPA was associated with body fatness as mediated by motor competence ($\beta_{\text{VPA}} = -0.042 \text{ SD}; 95\% \text{ CI: -0.063: -0.022}$) and fitness ($\beta_{\text{VPA}} = -0.074 \text{ SD}; 95\% \text{ CI: -0.105: -0.042}$). Moreover, VPA showed total association with body fatness ($\beta_{\text{VPA}} = -0.112 \text{ SD}; 95\% \text{ CI: -0.180: -0.043}$). In the analyses with VPA in the model, motor competence was directly associated with body fatness ($\beta_{\text{MC}} = -0.228 \text{ SD}; 95\% \text{ CI: -0.285: -0.171}$). Additionally, motor competence exhibited a significant association with body fatness as mediated by fitness ($\beta_{\text{MC}} = -0.141 \text{ SD}; 95\% \text{ CI: -0.174: -0.108}$), but not VPA ($\beta_{\text{MC}} = 0.001 \text{ SD}; 95\% \text{ CI: -0.008: 0.010}$). Motor competence also presented total association with body fatness ($\beta_{\text{MC}} = -0.369 \text{ SD}; 95\% \text{ CI: -0.429: -0.309}$). Fitness was associated with body fatness directly ($\beta_{\text{FIT}} = -0.216 \text{ SD}; 95\% \text{ CI: -0.264: -0.169}$) and totally ($\beta_{\text{FIT}} = -0.431 \text{ SD}; 95\% \text{ CI: -0.492: -0.370}$) (see Figure 4).

**Discussion**

To the best of our knowledge this is the first study to evaluate the longitudinal impact of PA, motor competence and VO$_{2\text{peak}}$ on body fatness in a seven-year follow-up, specifically using an a priori conceptual approach (Stodden et al. (2008)). All exposure variables were longitudinally associated, either directly or indirectly, with body fatness, and VO$_{2\text{peak}}$ had the strongest longitudinal total impact on body fatness. Around 50% of the association between VO$_{2\text{peak}}$ and body fatness was explained via the mediation role of VO$_{2\text{peak}}$ on the associations between PA (MVPA and VPA) and body fatness and motor competence and fatness. Furthermore, motor competence exhibited direct and mediated, via VO$_{2\text{peak}}$, association with body fatness. Moreover, motor competence.

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mediated the association between PA (MVPA and VPA) and body fatness. In addition, PA was not directly associated with body fatness, or mediated the association between motor competence and body fatness. PA was only associated with body fatness via VO$_{2peak}$ mediation. In conclusion, motor competence and VO$_{2peak}$ work in conjunction with PA to affect body fatness through childhood and early adolescence.

Physical activity (MVPA or VIG PA) was associated with body fatness, as proposed by Stodden et al. (2008), but only via mediation by motor competence and VO$_{2peak}$. Likewise, Martins et al. (2010) did not find an association between self-reported physical activity levels and body fatness when controlling for motor competence and cardiorespiratory fitness. Thus, the aforementioned results are similar to the non-significant direct impact of physical activity on body fatness observed in our analysis. These data also agree with the two other longitudinal studies that included both physical activity and cardiorespiratory fitness with body fatness (but not motor competence). Physical activity had either no impact or a weak longitudinal impact on body fatness when controlling for physical fitness (Aires et al. 2010; He et al. 2011). This is in contrast to data from several other longitudinal studies where physical activity was directly associated with decreased body fatness (six out of seven studies reviewed). However, physical fitness and motor competence were not included in the analysis of those six studies (Pate et al. 2013). In summary, our results indicated that physical activity and motor competence contributed to the development of VO$_{2peak}$ and impacted body fatness due to their relationship with VO$_{2peak}$ (mediation results).

Motor competence had both a direct and indirect (mediated by VO$_{2peak}$) inverse longitudinal impact on body fatness. These data agree with previous longitudinal data that used BMI as a weight status predictor (D’Hondt et al. 2013; D’Hondt et al. 2014; Martins et al. 2010). Specifically, Martins et al. (2010) assessed motor competence, self-reported PA and cardiorespiratory fitness (via 1 mile run/walk) and found that motor competence was the only variable to significantly influence BMI. D’Hondt et al. (2014) demonstrated a weaker effect of motor competence on BMI ($\beta$= -0.003 BMI z-scores), but only across two years of monitoring. It is likely that our measure of body fatness (skinfolds) allowed us to observe stronger relationships with motor competence than BMI would, as BMI is only a proxy for percent fat. Physical activity was not a mediator of the relationship between motor competence and BMI (D’Hondt et al. 2014) study, which it is similar to the non-significant mediation component of physical activity in the relationship between motor competence and body fatness shown in the current study. Thus, it appears that motor competence has independent, direct, longitudinal relationships with body fatness.

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From the three exposure variables tested in our model, VO\textsubscript{peak} had the highest total impact on body fatness, and it also mediated the impact that physical activity and motor competence had on body fatness. However, around 50% of the total impact of VO\textsubscript{peak} on body fatness was explained by VO\textsubscript{peak} mediating the effect of physical activity and motor competence on body fatness. Thus, the Stodden et al. (2008) conceptual framework has correctly predicted the mediation role of physical fitness in the relationships between motor competence, physical activity and body fatness as shown in these longitudinal data. According to our results, it seems plausible that while developing motor competence is inherently associated with physical activity, the capability to successfully participate in many different activities that inherently require adequate levels of motor competence probably generates more opportunities to be physically active, thus leading to higher cardiorespiratory fitness and decreased body fatness (Stodden et al. 2008). Subsequently, higher cardiorespiratory fitness would allow for longer participation, specifically in activities associated with moderate and vigorous activity. In fact, Ré et al. (2016) demonstrated that higher fitness has a major impact on soccer participation in recreational level adolescents, and the mediation role of fitness observed in our study supports this finding. Concomitantly, increased physical activity and increased motor competence likely function to assist in the development of cardiorespiratory fitness as physical activity and motor competence demonstrate consistent positive associations with fitness across childhood. Thus, the synergetic associations among physical activity, motor competence, VO\textsubscript{peak} and body fatness across childhood into adolescence noted in this study suggest the need to intervene in early childhood, by providing an environment where physical activities promote both motor competence and physical fitness might have greater sustained impact across childhood and into adolescence on unhealthy weight gain.

Our study has limitations to be considered in the interpretation of the results. While accelerometry is considered a reference method measure for physical activity in epidemiological studies, the limited measurement time of physical activity (four to seven days at each age – six, nine and 13 years of age) may not demonstrate true physical activity habits of children and may have influenced the strength of association with body fatness. In addition, from the three exposure variables, physical activity accelerometry represents the largest measurement error, which could have weakened the strength of relationships with physical activity and body fatness. Data from this study also might have been influenced by the intervention project that occurred in the initial three years of the project. However, compared to participants in the control arm of the original intervention study, the intervention demonstrated no significant impact on physical activity, motor competence, VO\textsubscript{peak} or body fatness levels (Bugge et al., 2015).
al. 2012) and the longitudinal results presented in this study were adjusted for the intervention factor. Unfortunately, we only have three time points of monitoring, which does not provide a truly clear picture of how the longitudinal associations among all the factors developed and how the strength of associations developed across time, and perceived motor competence was not collected as part of this study.

In terms of strengths it should be noted that this is the first longitudinal study to test the conceptual framework first proposed by Stodden et al. (2008), which intended to describe how physical activity, motor competence and health-related fitness would influence obesity risk across childhood and adolescence. In addition, the assessments in this study (actual VO\text{2peak}, motor competence, body fatness, and accelerometry derived physical activity) are the most complete and most objective set of measures for all variables that have been used in one study. Importantly, we were able to follow children for seven years during their childhood until early adolescence, which is the longest time frame where these types of data have been collected. This time frame also represents a period where obesity trajectories are solidified, and thus track into adulthood (Bass & Eneli 2015).

**Perspective**

Physical activity (only indirectly), motor competence and cardiorespiratory fitness collectively demonstrated a strong longitudinal impact on body fatness. Physical activity only influenced body fatness through VO\text{2peak} and motor competence, while motor competence presented direct and indirect (also mediated by VO\text{2peak}) impact on body fatness. From the three exposure variables, VO\text{2peak} demonstrated the greatest total impact on body fatness. Therefore, physical activity interventions focusing on the development motor competence and cardiorespiratory fitness in early childhood could have a sustainable impact on maintaining a healthy weight status, or even reducing adiposity across childhood and adolescence. Overall, it seems logical, as well as feasible, that interventions should strive to promote the development of fitness and motor competence through developmentally appropriate physical activities, as the synergistic interactions of all three variables are more likely to impact body weight status than focusing on only one variable.
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References


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Table 1 Mean (SD) physical and motor characteristics of participants by age and sex.

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<th>All</th>
<th>Boys</th>
<th>Girls</th>
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<td></td>
<td>6 years</td>
<td>9 years</td>
<td>13 years</td>
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<td>Age (years)</td>
<td>6.75 (0.37)</td>
<td>9.59 (1.07)</td>
<td>13.35 (0.34)</td>
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<td>MVPA* (min/day)</td>
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<td>72.97 (25.53)</td>
<td>53.20 (24.62)</td>
</tr>
<tr>
<td>VPA* (min/day)</td>
<td>28.28 (13.99)</td>
<td>29.94 (15.09)</td>
<td>20.75 (13.28)</td>
</tr>
<tr>
<td>KTK score</td>
<td>119.18 (27.66)</td>
<td>195.17 (34.64)</td>
<td>249.40 (29.41)</td>
</tr>
<tr>
<td>VO₂peak* (ml.kg⁻¹.min⁻¹)</td>
<td>46.71 (5.97)</td>
<td>49.06 (7.14)</td>
<td>49.27 (8.69)</td>
</tr>
<tr>
<td>Body fatness* (mm)</td>
<td>26.62 (9.97)</td>
<td>33.56 (16.46)</td>
<td>34.93 (16.83)</td>
</tr>
</tbody>
</table>

* p < 0.05 significant difference between boys and girls in all ages
Figure 1. Structured and pathways used to perform the analysis.

Legend: PA: Physical activity (Vigorous/moderate-to-vigorous physical activity). Solid lines represent direct pathways, and dotted lines represent indirect pathways.
Figure 2. Simplified example of the longitudinal association between MVPA and body fatness (S4SF), without any mediation effects noted. Other variables were tested similarly, and covariates and mediations were also examined (see Figure 1).

Legend: Solid lines – Association between the variables in a period of time; Dotted lines – adjustment on the calculation of the association because of dependency of a previous measure.
Figure 3 Standardized parameter estimates of the slope for the total, direct and indirect association between MVPA, motor competence, VO$_{2peak}$ and body fatness.

Legend: a) Black solid line and coefficients: direct impact of the exposures on body fatness; b) Blue dotted line and coefficients: the indirect impact of MVPA and motor competence on body fatness mediated by VO$_{2peak}$; c) Green dotted line and coefficients: indirect impact of MVPA and motor competence on body fatness mediated by motor competence and MVPA respectively; d) Red coefficients: the total impact of physical activity, motor competence and VO$_{2peak}$ on body fatness.
Figure 4 Standardized parameter estimates of the slope for the total, direct and indirect association between VPA, motor competence, VO\textsubscript{2peak} and body fatness.

Legend: a) Black solid line and coefficients: direct impact of the exposures on body fatness; b) Blue dotted line and coefficients: the indirect impact of VPA and motor competence on body fatness mediated by VO\textsubscript{2peak}; c) Green dotted line and coefficients: indirect impact of VPA and motor competence on body fatness mediated by motor competence and VPA respectively; d) Red coefficients: the total impact of physical activity, motor competence and VO\textsubscript{2peak} on body fatness.