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Modeling relationships between physical fitness, executive functioning, and academic achievement in primary school children

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ABSTRACT

Objectives: The relationship between physical fitness and academic achievement in children has received much attention, however, whether executive functioning plays a mediating role in this relationship is unclear. The aim of this study therefore was to investigate the relationships between physical fitness, executive functioning, and academic achievement, more specifically to test whether the relationship between physical fitness and academic achievement is direct or indirect, via executive functioning.
Design: Cross-sectional.
Method: This study examined 263 children (145 boys, 118 girls), aged 7–12 years, who performed tests on physical fitness, executive functioning, and academic achievement.
Results: In a structural equation model linking physical fitness to executive functioning and academic achievement there was a significant relationship between physical fitness and executive functioning ($r = .43$, $R^2 = .19$) and academic achievement ($r = .33$, $R^2 = .11$). Adding a relationship from executive functioning to academic achievement resulted in a non-significant direct link between physical fitness and academic achievement ($r = -.08$, $R^2 = .006$). However, a significant indirect relation through executive functioning persisted. The indirect relation between fitness and academic achievement ($r = .41$), was stronger than both the direct and total relation ($r = .33$).
Conclusion: Executive functioning thus served as a mediator in the relation between physical fitness and academic achievement. This highlights the importance of including executive functioning when studying the relationship between physical fitness and academic achievement in children.
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Introduction

While researchers and health professionals notice that children are increasingly less fit, teachers are observing that there is a growing concentration deficit and reduced attention in children (Budde, Voelcker-Rehage, Pietraßyk-Kendziorra, Ribeiro, & Tidow, 2008). In this context it is interesting to look at the relation between physical fitness and performance in the classroom. Physical fitness (fitness) is a set of attributes associated with the capacity to perform physical activities (Ortega, Ruiz, Castillo, & Sjöström, 2008). It refers to the full range of physical qualities and can be subdivided into various aspects like aerobic endurance, muscle strength and body composition (Ruiz et al., 2006). In children, fitness has not only been related to performance on academic achievement, but also to other cognitive functions. Some studies have found a positive relationship between aerobic endurance and academic achievement (Castelli, Hillman, Buck, & Erwin, 2007; Chomitz et al., 2009; Eveland-Sayers, Farley, Fuller, Morgan, & Caputo, 2009), or between aerobic endurance and aspects of higher order cognitive functions, e.g. executive functioning (Buck, Hillman, & Castelli, 2008; Hillman, Buck, Themanson, Pontifex, & Castelli, 2009; Pontifex et al., 2011). Executive functioning encompasses a subset of cognitive operations used to effortfully guide behavior towards a goal (Banich, 2009), and includes abilities such as inhibition, filtering interference, flexibility of action and strategy development. Executive functioning develops throughout childhood and adolescence and has been linked to academic achievement (Bull & Scerif, 2001).

Neuropsychological research shows that performance in executive functioning is mediated by the development of the prefrontal cortex (Stuss, 1992). Children show substantial improvements in executive functioning when the frontal brain regions mature, with rapid development between ages 7 and 9 (Anderson, 2002; Best, Miller, & Jones, 2009). A foundational component of executive

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functioning is cognitive flexibility (also called set-shifting). Cognitive flexibility is the ability to alternate attention between two simultaneous goals (Arbuthnott & Frank, 2000). The ability to shift between two tasks starts in infancy but develops into more complex switching capacity throughout childhood and into adulthood (Diamond, 2002). It is usually tested in set-switching tasks, in which the participant is asked to switch between two stimuli or to sort cards according to rules that change along the way (Best et al., 2009). Successful task switching requires inhibitory control of the currently irrelevant task set (Arbuthnott & Frank, 2000), and is found to be of importance in environments in which attentional demands are constantly changing.

Another important executive function is response planning or problem solving, which refers to the processes that facilitate the selection of task appropriate responses (Asato, Sweeney, & Luna, 2006). The ability to plan is a critical part of goal-oriented behavior and enables a child to direct and evaluate his or her behavior when confronted with a novel situation (Best et al., 2009). Tasks testing this ability require the child to plan multiple steps in advance and evaluate this plan while performing the actions (Best et al., 2009). Response planning involves multiple cognitive processes like response inhibition and working memory, and therefore reflects essential elements of executive functioning (Asato et al., 2006).

Both cognitive flexibility and response planning are frequently linked to the development of academic achievement in children, especially mathematics and reading (Best, Miller, & Naglieri, 2011). It is thought that improvements in executive functioning facilitate improvements in academic achievement (Best et al., 2009), or that adequate executive functioning develops prior to behaviors affecting academic achievement (Blair & Razza, 2007). Indeed, the ability to shift attention is likely to be important for moving between tasks and has been found to be involved in mathematics (Bull, Espy, & Wiebe, 2008) and reading performance (Van der Sluis, De Jong, & Van der Leij, 2007). Likewise, the ability to plan in order to solve a problem seems to be fundamental for mathematic skills (Sikora, Haley, Edwards, & Butler, 2002).

The link between fitness and executive functioning or academic achievement in children seems to be most valid for the aerobic fitness component of physical fitness. Aerobic fitness refers to the overall capacity of the cardiovascular and respiratory system to use oxygen, and the ability to carry out prolonged strenuous exercise (Ortega et al., 2008). Castelli et al. (2007) examined the relation between academic achievement and various aspects of fitness, including aerobic fitness, muscle fitness, flexibility and body composition. They found that only aerobic fitness and BMI were related to performance on reading and mathematics. Other studies also found that more fit children, based on performance on aerobic fitness tests, had better scores on academic achievement tests (Chomitz et al., 2009) and executive functioning tasks (Buck et al., 2008) than their lower fit peers. Research on neuro-electric activation patterns of cognition in children showed that more fit children, with greater aerobic fitness based on directly measured maximal oxygen consumption, were more accurate on executive functioning tasks compared to their lower fit peers (Hillman et al., 2009; Pontifex et al., 2011). In addition to the aerobic fitness component, studies in older adults also showed a positive relation between muscle strength and performance on executive functioning tasks (Cassilhas et al., 2007; Liu-Ambrose et al., 2010), but in children this possible relation is still unclear. Castelli et al. (2007) did not find a relation between muscle strength and academic achievement, however, in a study by Eveland-Sayers et al. (2009) a positive relationship was found between muscular fitness and mathematics scores. Also, Dwyer, Sallis, Blizzard, Lazarus, and Dean (2001) found an association between muscle force, muscle power and academic achievement, specifically with sit-ups and standing long jump, measuring trunk strength and explosive leg power respectively.

One possible theory explaining the relationship between aerobic fitness and executive functioning or academic achievement is the physiological fitness hypothesis, also called the cardiovascular fitness hypothesis. It states that regular exercise (either aerobic or non-aerobic exercise like muscular resistance or games without an aerobic component) will induce short and long term changes in brain regions critical to learning and memory, as a result of increased cerebral blood flow (Etnier et al., 1997). Acute bouts of exercise will result in an increase in the release of neurotransmitters responsible for synaptic transmission and plasticity like growth factors and neurotrophins (Best, 2010). In the long term, chronic exercise not only results in increased brain neurotransmitters, it may also result in permanent structural changes in the brain like new neuronal and vascular architecture (Hillman, Erickson, & Kramer, 2008). While most support for the physical fitness hypothesis comes from non-human studies, more and more research on humans show similar results (Pereira et al., 2007).

Taken together, several studies have described the relationships between fitness, executive functioning, and academic achievement separately. However, it remains unclear how these factors relate when investigated together. The goal of this study was therefore to simultaneously examine the relations between fitness (including both aerobic fitness and strength components), executive functioning, and academic achievement. Prior to the main analysis of the relationships between the three latent factors fitness, executive functioning, and academic achievement, confirmatory factor analysis (CFA) was used to test whether the observed measures served as good indicators of each factor. Once the three factors fitness, executive functioning, and academic achievement were clearly defined by their respective indicators, the relationships between the three factors were analyzed by putting them together in a model using structural equation modeling (SEM). To confirm relations found in previous studies, it was first tested whether fitness was related to executive functioning and academic achievement. It was hypothesized that fitness would be positively related to both executive functioning and academic achievement. Next, to address the main question, it was tested whether executive functioning plays a mediating role within the relation between fitness and academic achievement. That is, whether the relationship between fitness and academic achievement is direct or indirect. We hypothesized that executive functioning would serve as a mediator in the relation between fitness and academic achievement.

Method

Participants

Children from four primary schools in the northern Netherlands were recruited to participate in the study. In total, 263 typically developing children (145 boys, 118 girls) between the ages of 7 and 12 years old were included. Most of the children came from similar socioeconomic backgrounds; 12% of the children had a low or middle low socioeconomic status (SES) based on the education of the parents.[1] No statistical differences were found between boys and girls with respect to age, height, weight, Body Mass Index (BMI) and the percentage of children with normal weight and

[1] Low SES: One of the parents has finished primary school at most, the other parent finished a maximum of two years of other education in addition to primary school. Middle low SES: One or both of the parents have at least finished primary school and a maximum of two years of other education.

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