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# Relationships between physical activity, sedentary time, aerobic fitness, motor skills and executive function and academic performance in children

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ABSTRACT

*Background:* There is evidence for weak positive relationships between physical activity, aerobic fitness, and motor skills to executive functions and academic achievement. Studies assessing their relative importance to executive functions and academic performance are lacking. The purpose of this study was to examine the independent associations for moderate to vigorous physical activity and sedentary time, aerobic fitness, and motor skills with executive functions and academic performance in 10-year-old children.

*Method:* A linear mixed model was used to analyze cross-sectional data from 697 children from 57 schools in Norway.

*Results:* No relationships were observed between moderate to vigorous physical activity and executive functions or academic performance. The time spent sedentary was related to executive functions (standardized regression coefficient (β) 0.17–0.21, $p < 0.05$) and academic performance in English (β 0.22, $p < 0.05$) in boys. Aerobic fitness was associated with executive functions (β 0.16–0.21, $p < 0.05$) and academic performance (β 0.17–0.21, $p < 0.05$) in boys only. Motor skills were associated with most measures of executive functions in both girls (β 0.16–0.25, $p < 0.01$) and boys (β 0.13–0.22, $p < 0.05$) and academic performance in girls (β 0.13–0.16, $p < 0.05$).

*Conclusions:* The strongest independent associations were observed for motor skills to executive functions. Sex-specific associations were observed for aerobic fitness and motor skills. Thus, comprehensive physical activity targeted to increase both aerobic fitness and motor skills may have the potential to positively affect executive functions and academic performance.



## 1. Introduction

A physical active lifestyle during childhood seems to have a positive influence on the developing brain, in terms of brain structure and function. Hence, research on the role of physical activity to executive functions and academic performance shows promise (Donnelly et al., 2016; Khan & Hillman, 2014; Tomporowski, McCullick, Pendleton, & Pesce, 2015). While this research agenda has taken steps forward, more research is needed to better understand physiological and motor-cognitive assets embedded in various forms of physical activity that may help explain the relationships to executive functioning and academic performance (Best, 2010; Donnelly et al., 2016; Tomporowski et al., 2015). The current study aims to help fill this void by exploring the relationships of objectively measured physical activity level, sedentary time, aerobic fitness, and motor skills to executive functions and academic performance.

Executive functions can be defined as "the cognitive processes necessary for goal-directed cognition and behavior" (Best, 2010, p. 331) with core functions generally defined to involve inhibition and

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interference control, working memory and cognitive flexibility (Diamond, 2013; Miyake et al., 2000). At present, several theoretical lines of reasoning exists advocating that different modes of physical activity in terms of activity level (dose) and cognitive-motor challenge (type) may relate differently to the core executive functions. Supporting the view that level and type of physical activity may play a role, Best (2010) forwarded three mechanisms by which physical activity can affect executive functions: a) through physiological changes in the brain, b) through cognitive demands inherent in engaging games and c) through cognitive demands required to execute complex motor movement.

### 1.1. The role of physical activity level

Engaging in repetitive aerobic physical activity (e.g. running) can induce angiogenesis, increased blood volume, and upregulation of growth factors and neurothrophins (Best, 2010). Cross-sectional studies with objective measurements of physical activity have shown that moderate to vigorous physical activity (MVPA) has been associated with decreased reaction time (Syvaoja, Tammelin, Ahonen, Kankaanpaa, & Kantomaa, 2014) and improved executive attention (Booth et al., 2013). Furthermore, a sufficient level of MVPA can increase aerobic fitness (Armstrong, Tomkinson, & Ekelund, 2011), which might be a prerequisite to improve executive function (the cardiovascular fitness hypothesis) (Schmidt, Jager, Egger, Roebers, & Conzelmann, 2015). Current studies have found superior brain structure and function, coupled with increased performance on tasks of executive function in higher fit children compared to lower fit children (see Chaddock, Pontifex, Hillman, & Kramer, 2011; Donnelly et al., 2016; Khan & Hillman, 2014 for reviews). Although aerobic fitness arguably is a direct measure of the physiological strain induced by MVPA, these parameters represents different constructs (physical activity a behavior, and aerobic fitness a personal attribute with a genetic component) (Rowland, 2005; Schutte, Nederend, Hudziak, Bartels, & de Geus, 2016), meaning that it is important to determine their independent relationships with executive functions. Due to the increased measurement precision of aerobic fitness compared to physical activity (that inherently vary over time and is difficult to capture precisely) (Ekelund et al., 2007), the relationships of aerobic fitness to executive functions are expected to be stronger than those of physical activity.

Moderate to vigorous physical activity and sedentary time are separate dimensions of activity (Ekelund et al., 2007; Sedentary Behaviour Research Network, 2012) that may be associated with executive functions and academic performance in different ways. Sedentary time can be defined as any waking behavior while in a sitting or reclining posture requiring an energy expenditure $\leq$1.5 resting metabolic equivalents (Sedentary Behaviour Research Network, 2012). Few studies exists for the associations between sedentary behavior and cognitive health while accounting for levels of moderate to vigorous physical activity (Faulkner & Biddle, 2013) and evidence for the relationship between sedentary time and academic performance is lacking (Carson et al., 2016). Thus, more studies are needed on this area of research.

### 1.2. The role of type of physical activity

Gains obtained in motor skills performance through participation in group games and complex motor tasks may possibly induce neurogenesis in the hippocampus and physiological changes in the cerebellum. Furthermore, as group games and executive function tasks require similar cognitive skills, it is possible that skills acquired during complex motor tasks and cognitively demanding group games transfer to executive functions (Best, 2010). The close interrelationship between motor control and executive functions is furthermore underlined by 1) the co-activation between the prefrontal cortex, the cerebellum and the basal ganglia during several motor and cognitive tasks, 2) their similar developmental timetable (Diamond, 2000), and 3) their common underlying processes, such as sequencing, monitoring and planning (Roebers & Kauer, 2009; van der Fels et al., 2015).

Intervention studies manipulating the mental engagement in physical activity through enhancing the coordinative and cognitive demands have revealed superior effects on executive functions compared to physical activities without this enhancement (Crova et al., 2013; Pesce et al., 2016; Schmidt et al., 2015). For example, Pesce et al. (2016) showed that physical education with playful coordinative and cognitive enrichment improved inhibition, and that this improvement was mediated by motor coordination. In cross-sectional studies, weak positive associations have been found between motor skills and executive functions in children (Davis, Pitchford, & Limback, 2011; Roebers & Kauer, 2009). Studies reports inconsistency in which components of executive function that are affected by or associated with physical activity, which might be due to different components of executive function having different developmental trajectories (Best & Miller, 2010). Thus, examination of the genuine relationships between motor skills performance and individual aspects of executive functions are important to clarify.

### 1.3. Executive functions and academic performance

Executive functions are important for learning, and their relevance for academic performance in mathematics, English (reading, writing and spelling) and science is empirically documented (Barenberg, Berse, & Dutke, 2011; Best, Miller, & Naglieri, 2011; Bull & Scerif, 2001; St Clair-Thompson & Gathercole, 2006). As academic performance is a more global measure of cognition compared to executive functions, weaker relationships between physical activity, aerobic fitness, and motor skills to academic performance than to executive functions are expected. The current evidence has revealed positive, but weak, relationships for physical activity (Donnelly et al., 2016; Esteban-Cornejo, Tejero-Gonzalez, Sallis, & Veiga, 2015; Singh, Uijtdewilligen, Twisk, van Mechelen, & Chinapaw, 2012), aerobic fitness (Davis & Cooper, 2011; Donnelly et al., 2016; Lambourne et al., 2013), and motor skills (Haapala et al., 2014; Rigoli, Piek, Kane, & Oosterlaan, 2012), to academic performance. A major limitation, however, is that the evidence with few exceptions is based on self-reported physical activity levels. The results from cross-sectional studies using objective measures of physical activity are less consistent than the evidence on self-reported physical activity (Corder et al., 2015; Esteban-Cornejo et al., 2014; Kwak et al., 2009; Lambourne et al., 2013; LeBlanc et al., 2012; Syvaoja et al., 2013). Furthermore, there exists no clear pattern among the level and type of physical activity and specific subjects such as math, reading or spelling (Donnelly et al., 2016). Thus, exploring specific subjects may add knowledge to the evidence of the relationship between level and type of physical activity and academic performance.

Studies assessing the relative importance of physical activity, sedentary time, aerobic fitness, and motor skills to executive functions and academic performance, while also examining the relationship between executive functions and academic performance are lacking (Haapala, 2013; Khan & Hillman, 2014). Therefore, the purpose of the present study was to examine the independent associations for physical activity, sedentary time, aerobic fitness, and motor skills with executive function and academic performance in a sample of 10-year-old Norwegian girls and boys. From the hypotheses by Best (2010) and the current empirical