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Executive functions, visual-motor coordination, physical fitness and academic achievement: Longitudinal relations in typically developing children

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ABSTRACT

The present longitudinal study included different school readiness factors measured in kindergarten with the aim to predict later academic achievement in second grade. Based on data of N = 134 children, the predictive power of executive functions, visual-motor coordination and physical fitness on later academic achievement was estimated using a latent variable approach. By entering all three predictors simultaneously into the model to predict later academic achievement, significant effects of executive functions and visual-motor coordination on later academic achievement were found. The influence of physical fitness was found to be substantial but indirect via executive functions. The cognitive stimulation hypothesis as well as the automaticity hypothesis are discussed as an explanation for the reported relations.

1. Introduction

A major challenge in children's life is a successful transition from kindergarten to school. While some children manage this important transition easily, others face problems when trying to adapt to their novel school environment. In this context, researchers aim to identify and quantify so-called "school readiness factors", child characteristics that predict later academic achievement in kindergarten children. While traditionally, domain-specific precursors for writing, reading, and mathematics, such as phonological awareness and number sense, were in the focus of school readiness research, a broader conceptualization of school readiness is now discussed (Pianta, Cox, & Snow, 2007). From this perspective, different domain-general characteristics of the child contribute substantially to the prediction of early academic achievement and school adjustment. Especially higher order self-regulatory abilities, particularly executive functions, have repeatedly and consistently been documented as being an important indicator of school readiness (for a recent review see Blair & Raver, 2015). Apart from a strong focus on executive functions, other domain-general child characteristics have engaged researchers' interest: among other, fine motor skills and physical fitness (e.g., Cameron et al., 2012; Schmidt et al., 2017), which are interrelated with each other (e.g., Oberer, Gashaj, & Roebers, 2017). In the present approach, therefore, these three domain-general factors of kindergarteners' school readiness were included to longitudinally estimate their *relative* predictive power for academic performance in children's second school year. The literature on these three concepts will be discussed in the following paragraphs.

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1.1. Executive functions

As mentioned above, executive functions are an important school readiness factor and their importance for academic achievement is consistently being reported (e.g., Blair & Raver, 2015). According to Miyake et al. (2000), executive functions is an umbrella term unifying at least three distinguishable, yet interrelated cognitive functions: inhibition, shifting and updating. Inhibition refers to the ability to suppress automatic or pre-potent impulses or responses; shifting is defined as the ability to flexibly shift between mental sets, multiple tasks or rules; and updating is the ability sustain, update or manipulate a limited amount of information in working memory (Diamond, 2013).

1.2. Visual-motor coordination

Visual-motor coordination as well as visual-spatial integration are both considered to belong to the broader term of fine motor skills. Fine motor skills thereby refer to the coordination of small muscle movements. More precisely, fine motor performance is based on visual perception and motor coordination, with the need to integrate these two aspects (Cameron, Murrah, Cottone, & Grissmer, 2016; Carlson, Rowe, & Curby, 2013; Sorter & Kulp, 2003). Under the term visual-spatial *integration* and with tests like the copy design test, these skills have been found to be related to writing and "penmanship" in more general terms and to predict academic achievement longitudinally (Cameron et al., 2012; Carlson et al., 2013; Cornhill & Case-Smith, 1996; Feder & Majnemer, 2007; Grissmer, Grimm, Aiyer, Murrah, & Steele, 2010; Pitchford, Papini, Outhwaite, & Gulliford, 2016). Much less work has addressed visual-manual *coordination*, typically assessed with tasks of manual dexterity (Henderson, Sugden, & Barnett, 2007). Visual-motor coordination comprises the control of small finger movements without the strong focus on integrating visual information, too. Two existing studies on visual-motor coordination suggest a link to achievement, either directly (Pitchford et al., 2016) or indirectly (Kim, Duran, Cameron, & Grissmer, 2017), while another did not (Carlson et al., 2013). Thus, since the link between visual-motor integration and academic achievement has been established while the link between visual-motor coordination has not, the focus of the present approach was laid on visual-motor coordination.

1.3. Physical fitness

Physical fitness is another factor indicative of school readiness that has only very recently received research attention (e.g., Chomitz et al., 2009; Fedewa & Ahn, 2011; Lopes, Santos, Pereira, & Lopes, 2013; van der Niet, Hartman, Smith, & Visscher, 2014). This lack of evidence is surprising since physical fitness is a popular construct and is often targeted in intervention programs; uncovering the impact of physical fitness for outcomes beyond health related measures may help to establish fitness programs even for children (Fedewa & Ahn, 2011; Ortega, Ruiz, Castillo, & Sjöström, 2008; Vandongen et al., 1995). Physical fitness is commonly understood to be a multidimensional construct consisting of different components involved in the performance of physical activities like aerobic endurance, muscle strength or agility (Bös, 1987; Ortega et al., 2008). Although the relation between physical fitness and academic achievement is far from being fully understood, positive relations to academic achievement in school-aged children were reported for aerobic endurance cross-sectionally (Castelli, Hillman, Buck, & Erwin, 2007; Chomitz et al., 2009; Welk et al., 2010) and longitudinally (Sardinha et al., 2016), as well as cross-sectionally for muscle strength (Castelli et al., 2007; Eveland-Sayers, Farley, Fuller, Morgan, & Caputo, 2009). In addition, agility was reported to be important and predictive for academic achievement in school-aged children (Kurdek & Sinclair, 2001; Lopes et al., 2013). Taken together, the link between physical fitness and academic achievement is frequently reported. Especially aerobic endurance seems to be consistently linked to academic achievement. However, these studies may have overestimated the impact of physical fitness on academic achievement as other important factors have not been included in those studies. Simultaneously addressing the influence of these different child characteristics will allow to estimate their relative contribution, an important next step for research in this domain.

In this context, another important question remains unanswered: *how* are visual-motor coordination and physical fitness linked to academic achievement? In other words, the underlying mechanisms driving this link have only rarely been targeted. The most prominent theoretical explanation for the link between physical fitness and academic achievement is the cardiovascular fitness hypothesis suggesting that physical activity causes functional and structural changes in the brain (Khan & Hillman, 2014; North, McCullagh, & Tran, 1990). In fact, magnetic resonance imaging studies revealed that especially the brain regions that are important for learning, such as the hippocampus, are affected through physical activity (Chaddock-Heyman et al., 2016). Event-related brain potential studies suggest that fitter children show a more efficient allocation of attentional resources (Hillman, Kamijo, & Scudder, 2011) and fitter children were also reported to be more physically active, than physically less active children (Ruiz et al., 2006). Consequently, the physical fitness hypothesis is one explanation for the reported links between physical fitness and academic achievement.

Another theoretical explanation that has recently been attracting more attention is the cognitive stimulation hypothesis. It assumes that coordinative demanding physical activity (for example, learning new sports or coordinative skills) not only increases physical fitness, but also enhances higher-order cognitive control processes, namely, executive functions (Best, 2010; Moreau, Morrison, & Conway, 2015; Tomporowski, Davis, Miller, & Naglieri, 2008). Assuming that physically fitter children engage in more physical activity (see above; Ruiz et al., 2006), it is conceivable that those children not only exercise and improve their fitness, but that by these means they have also more opportunities for motor skill learning. Learning new motor skills can be coordinatively as well as cognitively demanding and seems to be one way to improve cognitive functions, especially executive functions (Moreau et al., 2015; Pesce et al., 2013; Schmidt, Jäger, Egger, Roebers, & Conzelmann, 2015). Since executive functions are known to be a strong