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The development of executive functioning across the transition to first grade and its predictive value for academic achievement

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ABSTRACT

Executive functions (EFs), used to guide goal-directed behavior, are essential for adequate classroom functioning. The current study aims to, (1) examine development and stability of three core EFs (working memory, inhibition, cognitive flexibility) across the transition to first grade; and (2) investigate the relationship of EFs with academic achievement, taking into account their multidimensionality and interconnections. EF tasks were administered at the end of kindergarten and first grade ($n = 89$) and standardized achievement tests at the end of first grade. Results indicate moderate to large growth and stability in working memory and cognitive flexibility and small improvements and stability in inhibition. Working memory predicted academic achievement, cognitive flexibility had a limited role and no additional contribution of inhibition was found. The current study suggests that the transitional period to first grade can be an important period to promote EF development, which in turn can support the prevention of later school problems.

1. Introduction

Executive functions (EFs) are the cognitive processes needed to control thoughts, behavior and emotions. There are three core-EFs, working memory, inhibition and cognitive flexibility, that start to develop early in life and form the basis for complex EFs such as planning and organizing (Diamond, 2013; Garon, Bryson, & Smith, 2008; Zelazo & Carlson, 2012). EFs allow us to perform goal-directed actions and deliberately respond to our environment. As such, children use executive functions at school throughout the day, in a variety of situations, for example, when following complex instructions, during social contact, or in mathematics or reading. Previous research has shown, for example, positive relations between EFs and academic achievement (e.g., Alloway & Alloway, 2010; Welsh, Nix, Blair, Bierman, & Nelson, 2010). Because of the importance of executive functions in everyday school life, it is critical to understand EF development and the outcomes related to ill-developed EFs.

Understanding EF development is challenging as EF refers to a complex multidimensional construct, consisting of different core EFs, which in itself can be broken down in different subcomponents (see Table 1 for a brief overview based on Baddeley, 1992; Bari & Robbins, 2013; Diamond, 2013; Garon et al., 2008). Although there is now general agreement about the multidimensionality of the core EFs (e.g., Diamond, 2013; Gandolfi, Viterbori, Traverso, & Usai, 2014; Garon et al., 2008), most studies investigating EF development and its outcomes do not take into account the broad scope of EF subcomponents, especially in the case of inhibition and cognitive flexibility. This limits our insights in the development of the core EFs and how they relate to important child outcomes, such as academic achievement. The current study investigates the development of the core EFs at the time of transitioning from kindergarten to first grade, as this is an important moment in EF development. Additionally, the relationship of the core EFs with different aspects of academic achievement (reading, spelling and mathematics) is examined. Specific attention is paid to the multidimensional nature of the core EFs, by thoroughly measuring different subcomponents of working memory, inhibition and cognitive flexibility.

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Table 1
Overview of subcomponents distinguished within the core EFs.

Core EF	Subcomponent	Description
Working memory	Phonological loop	The ability to temporarily hold and rehears verbal information.
	Visuospatial sketchpad	The ability to temporarily hold and rehears visuospatial information.
	Central executive	The ability to process and manipulate information from different memory systems.
Inhibition	Cognitive inhibition	The ability to focus on relevant stimuli and thoughts and ignore irrelevant ones.
	Behavioral inhibition	The ability to constrain a dominant or automatic response.
Cognitive flexibility	Fluency	The ability to easily generate ideas and flexibly use those ideas in order to fluently generate responses.
	Shifting	The ability to shift between different cognitive sets or responses.

1.1. Development of executive functions

EF development depends on the development of the brain, specifically the prefrontal cortex (De Luca & Leventer, 2008), as well as environmental stimulation (Hughes, 2011). The three core EFs start to develop in the first year of life. Their development is characterized by alternating periods of rapid and gradual growth, with a first important growth spurt between the ages of 2 and 8. During this period children make the transition to formal schooling, which is accompanied by environmental changes and greater demands placed on children's EFs (Cuevas, Hubble, & Bell, 2012). The core EFs continue to develop, at least until late adolescence (Best, Miller, & Jones, 2009; De Luca & Leventer, 2008; Diamond, 2013; Garon et al., 2008).

Although a general pattern can be seen in EF development, research suggests different developmental trajectories for different core EFs (Best et al., 2009; Diamond, 2013; Garon et al., 2008; Hughes, 2011). Inhibition emerges very early (approximately from the age of 8 months on; Garon et al., 2008), shows especially strong growth in the preschool period and improves more modestly from the age of 5 onwards (Best et al., 2009; Garon et al., 2008). While working memory also starts to develop very early (approximately from the age of 9 months; Diamond, 2013), it has a more linear and prolonged developmental trajectory with strong improvements also occurring after the preschool period (Best et al., 2009). Cognitive flexibility, on the other hand, starts to develop later (around the age of 3) and still shows dramatic improvements during the school age years (Best et al., 2009; Diamond, 2013; Hughes, 2011).

Besides development in terms of average growth, interindividual stability is another aspect of EF development. If EFs are stable in a developmental period, later EF performance can be predicted by earlier EF performance. In other words, children with relatively high (or low) EF scores will remain high (or low) performances in the future. EF development in this sense has been far less studied (Polderman et al., 2007). Previous research shows low to moderate stability in EF performance in children between the age of 5 and 12 ($r = 0.20$-0.41 - e.g., Harms, Zayas, Meltzoff, & Carlson, 2014; Polderman et al., 2007). A study of Roebers, Röthlisberger, Cimeli, Michel, and Neuenschwander (2011) suggests EFs to be somewhat less stable for children who make the transition to first grade, possibly due to the considerable changes in children's learning environment.

1.2. Executive functioning and school achievement

Because of EFs' importance for goal-directed behavior, they are essential in a large number of life domains, including education (Diamond, 2013). Numerous studies have already shown a link between EF and academic achievement. Within academic achievement, both language skills, such as reading and spelling, and mathematics skills show associations with EFs, from an early age (e.g., Welsh et al., 2010).

Whereas most studies have examined this relationship with EF as a general construct (e.g., Cameron et al., 2012; Willoughby, Kupersmidt, Voegler-Lee, & Bryant, 2011), some studies investigated the role of specific EFs for (aspects of) academic achievement. These studies indicate that different core EFs might relate differently to academic achievement. Working memory has been most consistently related to both reading (e.g., Alloway & Alloway, 2010; Christopher et al., 2013; Nevo & Breznitz, 2011) and mathematics achievement (Alloway & Alloway, 2010; Attout & Majerus, 2014; De Smedt et al., 2009). For inhibition results are mixed. Most studies suggest relationships between inhibition and reading and language (Blair & Razza, 2007; Monette, Bigras, & Guay, 2011) and mathematics (Blair & Razza, 2007; Clark, Pritchard, & Wodward, 2010; Gilmore et al., 2013), while a few studies report no associations with reading and language abilities (Christopher et al., 2013) nor with mathematics (Lee et al., 2012; Monette et al., 2011). Most studies concluding that inhibition is important for academic achievement have measured inhibition with a single task and, as such, have only examined a specific aspect of inhibition. This raises questions about whether inhibition, with all its subcomponents, is truly related to academic achievement. Moreover, studies often investigate inhibition in isolation and do not take into account the other core EFs. Although different EFs can be distinguished, even at a young age (e.g., Usai, Viterbori, Traverso, & de Franchis, 2014; Van der Ven, Kroesbergen, Boom, & Leseman, 2013), they are also interconnected, especially inhibition and working memory (Diamond, 2013). Blair and Razza (2007) showed that inhibition was related to academic achievement when shifting (a component of cognitive flexibility was taken into account). In another study all three EFs were related to mathematics and reading when examining them simultaneously (Bull, Espy, & Wiebe, 2008). However, these studies did not take into account the different subcomponents in these EFs. It is thus unclear whether inhibition has an unique contribution to the prediction of academic achievement over the other EFs such as working memory. Cognitive flexibility was unrelated to reading and language abilities (Blair & Razza, 2007; Monette et al., 2011) and mathematics (Lee et al., 2012; Monette et al., 2011; Blair & Razza, 2007; see Clark et al., 2010 for an exception) in previous studies. However, previous studies have used only a limited range of tasks measuring cognitive flexibility, focusing mainly on tasks assessing attention shifting. Other components such as, fluency are most often not taken into account.

Thus, although the relations between EFs and academic achievement have been frequently examined, most studies use few tasks to measure EFs, especially in the case of inhibition and cognitive flexibility (e.g., Blair & Razza, 2007; Clark et al., 2010). Additionally, there is a limited amount of studies that examine the influence of the different core EFs on academic achievement simultaneously. As a consequence, it is unclear if the core EFs are uniquely related to academic achievement when all subcomponents are taken into account. This is important, as these insights can indicate whether or not it is useful to stimulate specific core EFs in order to prevent or target academic problems.