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Foundations of mathematics and literacy: The role of executive functioning components

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ABSTRACT

The current study investigated the relations between the three cognitive processes that comprise executive functioning (EF)—response inhibition, working memory, and cognitive flexibility—and individual components of mathematics and literacy skills in preschool children. Participants were 125 preschool children ranging in age from 3.12 to 5.26 years ($M = 4.17$ years, $SD = 0.58$). Approximately 53.2% were female, and the sample was predominantly Caucasian (69.8%). Results suggest that the components of EF may be differentially related to the specific components of early mathematics and literacy. For mathematics, response inhibition was broadly related to most components. Working memory was related to more advanced mathematics skills that involve comparison or combination of numbers and quantities. Cognitive flexibility was related to more conceptual or abstract mathematics skills. For early literacy, response inhibition and cognitive flexibility were related to print knowledge, and working memory was related only to phonological awareness. None of the EF components was related to vocabulary. These findings provide initial evidence for better understanding the ways in which EF components and academic skills are related and measured. Furthermore, the findings provide a foundation for further study of the components of each domain using a broader and more diverse array of measures.

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Introduction

During the preschool years, children undergo rapid changes in their cognitive and academic functioning (Diamond, 2002; Ginsburg, Klein, & Starkey, 1998; Zelazo & Carlson, 2012). Executive functioning (EF), early mathematics, and emergent literacy have been identified as important precursors for academic success (Duncan et al., 2007) and, thus, are core aspects of school readiness. Successful acquisition of these skills, and the sub-skills within each of these domains, has long-lasting positive relations with later achievement and career success (Moffitt et al., 2011; National Early Literacy Panel [NELP], 2008; National Mathematics Advisory Panel [NMAP], 2008). These domains are related to, and predictive of, one another (Fuhs, Nesbitt, Farran, & Dong, 2014); most notably, children's early EF skills have been shown to support their acquisition of mathematics and literacy skills (Schmitt, McClelland, Tominey, & Acock, 2015; Tominey & McClelland, 2011).

Typically, relations between EF and academic domains are examined at a broad level (Bull, Espy, Wiebe, Sheffield, & Nelson, 2011; Fuhs et al., 2014; McClelland et al., 2007). Yet, these domains are each conceptualized as having distinct, but related, components (Lonigan, Burgess, & Anthony, 2000; Miyake, Friedman, Emerson, Witzki, & Howerter, 2000; Purpura & Lonigan, 2013) that vary in their complexity and cognitive requirements; thus, the distinct constructs within each domain may be differentially related to the constructs in the other domains. The central focus of this study was to investigate the relations among EF, mathematics, and literacy skills at a relatively fine-grained level by focusing on the individual components of each construct.

Development of school readiness skills

Executive functioning

EF is generally defined as the adaptive, goal-directed control of thoughts, behaviors, and emotions (Best & Miller, 2010). It has also been identified as a higher level cognitive system that integrates and controls skills from more basic levels such as processing speed and memory span (Demetriou, Mouyi, & Spanoudis, 2010). EF is currently conceptualized as being composed of three related, yet distinct, cognitive processes that enable individuals to exert better control over information processing and behaviors: response inhibition (RI), working memory (WM), and cognitive flexibility (CF) (Miyake et al., 2000). RI refers to the ability to override a dominant or prepotent response in favor of a more adaptive one (Dowsett & Livesey, 2000). WM involves the simultaneous maintenance and manipulation of information (Gathercole, Pickering, Knight, & Stegmann, 2004). Finally, CF includes maintaining focus and flexibly adapting to changing goals or stimuli (Rueda, Posner, & Rothbart, 2005). There are two broad theoretical perspectives for the dimensionality of EF, both of which have empirical support (Garon, Bryson, & Smith, 2008). The first is that EF is a unitary construct (Hughes, Ensor, Wilson, & Graham, 2010; Wiebe, Espy, & Charak, 2008), and the second is that it is multidimensional in structure (Lerner & Lonigan, 2014; Lonigan, Lerner, Goodrich, Farrington, & Allan, 2016; van der Ven, Kroesbergen, Boom, & Leseman, 2013). Based on recent evidence that the components of EF may be dissociable (Lonigan et al., 2016; Miller, Geisbrecht, Müller, McInerney, & Kerns, 2012) and differentially predict academic outcomes (McClelland et al., 2014), we explored the three components of EF as unique predictors of academic skills.

Although EF develops across the life span, the preschool years are often thought of as a sensitive period for EF development because of rapid changes in the prefrontal cortex between the ages of 2 and 5 years (Zelazo & Müller, 2011). The cognitive complexity and control (CCC) theory (Frye, Zelazo, & Burack, 1998) is often used as a framework for understanding the development of EF. In this theory, it is posited that age-related changes in EF occur during developmental transitions in early childhood through a process that includes increases in cognitive and behavioral control through the acquisition of more complex rule systems (Zelazo, Müller, Frye, & Marcovitch, 2003). The acquisition of more complex rule systems likely allows for the development of more complex EF skills and, thus, potentially the use of these EF skills to support development in other areas.

Although there is scant evidence regarding the developmental progressions of the three EF skills (with the exception of clear linear growth during childhood), theoretical perspectives suggest that