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Executive function and magnitude skills in preschool children



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ABSTRACT

Executive function (EF) has been highlighted as a potentially important factor for mathematical understanding. The relation has been well established in school-aged children but has been less explored at younger ages. The current study investigated the relation between EF and mathematics in preschool-aged children. Participants were 142 typically developing 3- and 4-year-olds. Controlling for verbal ability, a significant positive correlation was found between EF and general math abilities in this age group. Importantly, we further examined this relation causally by varying the EF load on a magnitude comparison task. Results suggested a developmental pattern where 3-year-olds' performance on the magnitude comparison task was worst when EF was taxed the most. Conversely, 4-year-olds performed well on the magnitude task despite varying EF demands, suggesting that EF might play a critical role in the development of math concepts.

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Introduction

Executive function (EF) refers to higher order cognitive abilities needed for self-control, including inhibition of incorrect responses, attention shifting, and updating information in working memory (Miyake & Friedman, 2012; Miyake et al., 2000). These skills undergo considerable development during the preschool period and beyond, and they impact later abilities (Carlson, Zelazo, & Faja, 2013). During recent years, it has been suggested that EF skills are important for mathematical understanding

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(see Raghobar, Barnes, & Hecht, 2010, and Yeniad, Malda, Mesman, van Ijzendoorn, & Pieper, 2013, for reviews). However, considerable questions remain about the causal role of EF in mathematical proficiency and how EF skills relate to mathematical understanding at different ages, particularly as EF and mathematics skills become more automatic over the course of development. Is EF necessary for mathematical understanding? Does EF play a larger role in obtaining mathematical skills earlier in acquisition or later? How does proficiency of mathematics skills influence their relation to EF? Can improving EF skills lead to improvements in mathematical performance? These and other questions remain open.

An understanding of the relation between mathematical understanding and EF at an early age is important because both skills have an impact on later achievement. Individual differences in EF skills in preschoolers have been shown to predict better social emotional coping during adolescence, higher SAT scores, and adult outcomes such as higher sense of self-worth, higher educational achievement, better coping with stress, and reduced likelihood of drug use (Ayduk et al., 2000; Moffitt et al., 2011; Shoda, Mischel, & Peake, 1990). Similarly, research has consistently shown that early mathematics skill is a particularly strong predictor of later educational success. A meta-analysis showed that the relation between early performance (school entry) and academic achievement during middle school was twice as strong for mathematics skill than for reading skill (Duncan et al., 2007).

Despite the documented importance of EF to mathematical skills, few studies have examined the relation between EF and mathematics ability in young children, although the development of both skills has been studied separately. Some researchers have argued that basic mathematics skills (e.g., arithmetic) exist during infancy (e.g., McCrink & Wynn, 2004), and evidence suggests that informal skills necessary for later math proficiency, including cardinality understanding, counting skills, and basic arithmetic, develop during the preschool years (Gelman & Gallistel, 1978; Sophian, 1996). Importantly, EF skills also develop rapidly during this time as attentional and reflective abilities improve (Carlson, 2005; Garon, Bryson, & Smith, 2008; Zelazo et al., 2003). It seems highly probable on a theoretical basis that these trajectories are related (Noël, 2009). For example, learning to count sequentially involves holding earlier information in mind and updating it with new information as well as inhibiting interference from other numbers (Raghobar et al., 2010). Later, becoming flexible and proficient with new operations requires selective attention to, and inhibition of, previously learned operations (e.g., avoiding the error of answering $3 \times 3 = 6$; Yeniad et al., 2013).

In the few studies exploring the relation between developing trajectories in mathematics and EF, researchers have found promising associations (Bull, Espy, & Wiebe, 2008; Bull, Espy, Wiebe, Sheffield, & Nelson, 2011; Clark, Pritchard, & Woodward, 2010; Clark, Sheffield, Wiebe, & Espy, 2013; Espy et al., 2004). In a sample of preschool children (average age 4 years), researchers found that working memory and inhibition were related to math ability (as assessed by the Woodcock–Johnson III [WJ-III] Applied Problems subtest), but only inhibition (or actively suppressing processes to better control attention, behavior, thoughts, and/or emotions) remained a unique predictor after controlling for the other EF skills and general intelligence (Espy et al., 2004). Interestingly, shifting skills at preschool were not found to be related to math skills. Using growth curve modeling starting at 4.5 years of age and continuing for 3 years, researchers showed that children with higher EF scores (as assessed by a battery including working memory and attention measures) had better performance on national math tests after controlling for reading ability (Bull et al., 2008). Similarly, strong associations were shown between an EF battery measured at 3 years and math achievement in kindergarten (Clark et al., 2013). This work suggests that a unique relation between EF and mathematical development at this young age may exist, where EF might be playing a particularly important role as both of these skills are undergoing important developments. However, the correlations presented in these studies are susceptible to confounds such as influences of IQ or verbal abilities and/or variations in early educational experiences. Thus, rigorous experimental evidence is needed to better understand whether, and if so how, EF aids mathematical development.

Recent evidence suggests that EF skills are not differentiated early in development and act more like a unitary system at preschool ages (Bull & Lee, 2014; Lee, Bull, & Ho, 2013; Wiebe et al., 2011). Confirmatory factor analysis has suggested that single-factor models are a better fit for data from preschool-aged children (Wiebe, Espy, & Charak, 2008) than three-factor models (i.e., shifting, updating, and inhibition) that have been found to best fit in adults (Miyake & Friedman, 2012; Miyake et al.,

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