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The role of executive attention in the acquisition of mathematical skills for children in Grades 2 through 4

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ABSTRACT

We examined the role of executive attention, which encompasses the common aspects of executive function and executive working memory, in children's acquisition of two aspects of mathematical skill: (a) knowledge of the number system (e.g., place value) and of arithmetic procedures (e.g., multi-digit addition) and (b) arithmetic fluency (i.e., speed of solutions to simple equations such as 3 + 4 and 8 – 5). Children in Grades 2 and 3 ($N = 157$) completed executive attention and mathematical tasks. They repeated the mathematical tasks 1 year later. We used structural equation modeling to examine the relations between executive attention and (a) concurrent measures of mathematical knowledge and arithmetic fluency and (b) growth in performance on these measures 1 year later. Executive attention was concurrently predictive of both knowledge and fluency but predicted growth in performance only for fluency. A composite language measure predicted growth in knowledge from Grade 2 to Grade 3. The results support an important role for executive attention in children's acquisition of novel procedures and the development of automatic access to arithmetic facts.

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Introduction

A range of cognitive factors influence children's learning of mathematical concepts, procedures, and facts. Of these various cognitive predictors, researchers have found that *attention*, as indexed by constructs such as executive working memory, working memory capacity, executive function, spatial attention, and controlled attention, seems to be particularly important (Bull, Espy, & Wiebe, 2008; Geary, 2010; Raghubar, Barnes, & Hecht, 2010). However, as noted by Raghubar and colleagues (2010), although many studies have shown concurrent correlations between attentional abilities and various mathematical measures, relatively few have considered longitudinal relations (Bull et al., 2008; Geary, Hoard, & Nugent, 2012; Hecht & Vagi, 2010; Mazzocco & Kover, 2007; Steele, Karmiloff-Smith, Cornish, & Scerif, in press; Swanson, 2006a). Longitudinal studies are important for showing how cognitive skills might influence growth in mathematical performance. Accordingly, the goal of the current analyses was to examine the relation between executive attention and children's acquisition of different aspects of mathematical learning using a short-term longitudinal design.

Executive functions—as reflected in children's ability to successfully execute goal-directed behavior, inhibit attention to irrelevant information, shift between response sets, and update information in immediate memory—appear to be crucial in the acquisition of complex cognitive tasks such as mathematics and reading (Best & Miller, 2010; Bull et al., 2008; Engle, 2002; Raghubar et al., 2010). Similarly, the central executive component of working memory is a reliable correlate of individual differences in mathematical performance for children and adults (DeStefano & LeFevre, 2004; LeFevre, DeStefano, Coleman, & Shanahan, 2005; Raghubar et al., 2010). These two attentional constructs, executive function and the central executive of working memory, have developed differently in the neuropsychological and cognitive literatures but share many conceptual similarities. McCabe, Roediger, McDaniel, Balota, and Hambrick (2010) used the term *executive attention* to describe the common elements of these constructs that predict complex cognitive tasks. Executive attention is assumed to index the fundamental control processes that are necessary in many complex cognitive tasks, including inhibition of competing responses, goal maintenance, and response selection (Engle, 2002; Kane, Conway, Hambrick, & Engle, 2007; Kane & Engle, 2003; McCabe et al., 2010). Because these aspects of attentional control seem to be very relevant to mathematical performance, we focused on executive attention as the construct likely to capture the role of individual differences in attention for distinct aspects of mathematical skill (Barrett, Tugade, & Engle, 2004; Best & Miller, 2010; Engle, 2002; McCabe et al., 2010; Wiebe, Espy, & Charak, 2008).

We hypothesized that executive attention is important in the development of two broad aspects of mathematical performance: (a) conceptual and procedural aspects of mathematical *knowledge* and (b) arithmetic *fluency*. The term *mathematical knowledge* refers to children's knowledge of Arabic and verbal numbers (i.e., symbolic number system knowledge) and also to their knowledge of calculation procedures (i.e., the series of problem solving steps involved in arithmetic operations on a wide range of problems, e.g., multi-digit subtraction problems). In contrast, fluency refers to latencies for solving single-digit arithmetic problems such as $3 + 4$ and $8 - 5$. By Grade 2, children are skilled at using counting to solve addition and subtraction problems (Wu, Meyer, & Maeda, 2008). Children's continued improvement on these facts reflects the extent to which children use memory retrieval rather than counting-based solutions or other procedures to solve arithmetic problems (Cumming & Elkins, 1999; Geary, 2010; Geary et al., 2012; Wu et al., 2008). In summary, knowledge and fluency are assumed to be differentiable components of mathematical skill.

What evidence is there that mathematical knowledge and fluency may be related to individual differences in executive attention? Bull and colleagues (2008) found that executive attention (measures of inhibition, shifting, and updating) and working memory (visual–spatial span and backward digit span) assessed in children in kindergarten were predictive of their performance on mathematics and reading tests 1 to 5 years later, with larger correlations between 7 and 9 years of age than between 5 and 7 years of age. Bull and colleagues tested the predictive relations of the various attentional tasks individually and found a complex pattern that differed for mathematics and reading outcomes. These