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Identifying the cognitive predictors of early counting and calculation skills: Evidence from a longitudinal study

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ABSTRACT

The extent to which phonological, visual–spatial short-term memory (STM), and nonsymbolic quantitative skills support the development of counting and calculation skills was examined in this 14-month longitudinal study of 125 children. Initial assessments were made when the children were 4 years 8 months old. Phonological awareness, visual–spatial STM, and nonsymbolic approximate discrimination predicted growth in early calculation skills. These results suggest that both the approximate number system and domain-general phonological and visual–spatial skills support early calculation. In contrast, only performance on a small nonsymbolic quantity discrimination task (where the presented quantities were always within the subitizing range) predicted growth in cardinal counting skills. These results suggest that the development of counting and the development of calculation are supported by different cognitive abilities.

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Introduction

Learning to count and learning to calculate are vital first steps toward mathematical competence. Theoretical models (Krajewski & Schneider, 2009; LeFevre et al., 2010) have identified verbal, visual–spatial, and quantitative abilities as important independent predictors of mathematical development. The current study examined the influence of these abilities on the development of early number skills. The extent to which phonological awareness, visual–spatial short-term-memory (STM), and nonsymbolic quantitative skills predict *growth* in counting and calculation was examined.

Development of counting and calculation

Young children develop their counting and calculation skills through informal everyday experiences and later through formal school-based instruction. *Sequential counting* refers to the ability to recite the number word sequence and acknowledge the position of a number word in this sequence without necessarily understanding its cardinal meaning (Fuson, 1992; Gelman & Gallistel, 1978). The initial stages of sequential counting often develop before children enter formal schooling (Case & Griffin, 1990; Gelman & Gallistel, 1978; Mix, Sandhofer, & Baroody, 2005; Siegler, 1991; Spelke, 2000; Wynn, 1992). Gradually, children develop the ability to apply their knowledge of the number word sequence to enumerate sets (Gelman, Meck, & Merkin, 1986; Wynn, 1992). This serial quantification process is referred to as *cardinal counting* and requires mapping each number word onto each item in a set in one-to-one correspondence to acknowledge the exact number of items in a collection (Fuson, 1988, 1992; Gelman & Gallistel, 1978). Many preschool children can also complete nonverbal calculations where the quantities are represented by objects (Barth, La Mont, Lipton, & Spelke, 2005; Huttenlocher, Jordan, & Levine, 1994; Jordan, Huttenlocher, & Levine, 1992; Levine, Jordan, & Huttenlocher, 1992; Rasmussen & Bisanz, 2005; Starkey & Gelman, 1982; Zur & Gelman, 2004). However, fewer preschool children are able to perform *formal calculations* (involving number words or symbols). Proficiency with formal calculations increases dramatically during the first years of schooling (Jordan et al., 1992; Levine et al., 1992; Rasmussen & Bisanz, 2005). The importance of these number skills is supported by empirical studies indicating that both early counting (Aunola, Leskinen, Lerkkanen, & Nurmi, 2004; Johansson, 2005) and calculation (Aunio & Niemivirta, 2010; Krajewski & Schneider, 2009; LeFevre et al., 2010) are effective predictors of later mathematical attainment. Furthermore, the establishment of secure counting and calculation skills is a core aim of early primary curricula (e.g., Department of Education & United Kingdom, 2014; Ministry of Education Singapore, 2012; National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010). It is important to understand the cognitive basis of counting and calculation because both are fundamental building blocks of early mathematics and key topics during the first years of children's education.

Theoretical models of number processing and mathematical development

Dehaene's triple-code model of number processing (Dehaene, Piazza, Pinel, & Cohen, 2003; Dehaene, Spelke, Stanescu, Pinel, & Tsivkin, 1999) identifies three different types of representations used during mathematical tasks. It is proposed that all numerical tasks involve the processing of abstract numerical representations that are associated with neural activity in the intraparietal sulcus. Visual–spatial or phonological representations may also be recruited, depending on the nature of the task. For example, phonological representations are used in tasks such as arithmetic fact retrieval, whereas visual–spatial representations are used in tasks such as number comparison where reference to an internal number line is required. Dehaene's model has influenced developmental models of early mathematics, with both LeFevre et al.'s (2010) pathways model and Krajewski and Schneider's (2009) arithmetical development model proposing that phonological processing, visual–spatial STM, and quantitative skills differentially influence the development of different number skills. These cognitive skills, therefore, form the focus of the current study.