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Processes in the development of mathematics in kindergarten children from Title 1 schools

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A B S T R A C T

This study examined how well nonverbal IQ (or fluid intelligence), vocabulary, phonological awareness (PA), rapid autonomized naming (RAN), and phonological short-term memory (STM) predicted mathematics outcomes. The 208 participating kindergartners were administered tests of fluid intelligence, vocabulary, PA, RAN, STM, and numeracy in the fall of kindergarten, whereas tests of numeracy and applied problems were administered in the spring of kindergarten. Fall numeracy scores accounted for substantial variation in spring outcomes (R^2 values = .49 and .32 for numeracy and applied problems, respectively), which underscores the importance of preschool math instruction and screening for mathematics learning difficulties on entry into kindergarten. Fluid intelligence and PA significantly predicted unique variation in spring numeracy scores (ΔR^2 = .05) after controlling for autoregressive effects and classroom nesting. Fluid intelligence, PA, and STM significantly predicted unique variation in spring applied problems scores (ΔR^2 = .14) after controlling for autoregressive effects and classroom nesting. Although the contributions of fluid intelligence, PA, and STM toward math outcomes were reliable and arguably important, they were small.

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Introduction

Early math achievement is critical for placing children on a positive educational trajectory. Children who start behind in mathematics tend to stay behind (Duncan et al., 2007; Jordan, Kaplan, Ramineni, & Locuniak, 2009; Stock, Desoete, & Roeyers, 2010; Toll, Van der Ven, Kroesbergen, & Van Luit, 2011). In particular, early difficulties with whole numbers interfere with learning fractions, which subsequently impedes algebraic learning (National Mathematics Advisory Panel, 2008). Indeed, one of the strongest predictors of later school achievement is early math achievement (Duncan et al., 2007), predicting children's reading achievement better than early literacy skills (Duncan & Magnuson, 2011; Duncan et al., 2007; Koponen, Salmi, Eklund, & Aro, 2013) and predicting math achievement through age 15 years (Watts, Duncan, Siegler, & Davis-Kean, 2014). Furthermore, evidence of widespread differences in early math achievement (Geary, 2006; Mullis, Martin, & Arora, 2012; National Research Council [NRC], 2009; Sarama & Clements, 2009) and that children from low-income and minority backgrounds persistently score below their middle-income peers (Geary, 1993; Griffin, Case, & Siegler, 1994; Lee, 2002; National Assessment of Educational Progress, 2007, 2013; NRC, 2009; Sarama & Clements, 2009; Saxe, Guberman, & Gearhart, 1987; Siegler, 1993) has led to attempts to improve math education in the United States. For example, comprehensive math standards that begin in kindergarten, called the *Common Core State Standards for Mathematics,* were recently adopted by 42 states and the District of Columbia (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010).

Given the importance of early math achievement and the persistent achievement gap between children from low-income and minority backgrounds and their majority peers, it is important to advance the field's understanding of cognitive and linguistic processes underlying its early development in these children. This knowledge can be used to inform instructional math programs and screenings for mathematics learning difficulties. There is growing consensus concerning which cognitive and linguistic processes are important to early math development (and math disabilities) (e.g., Fletcher, Lyon, Fuchs, & Barnes, 2006; Geary, 1994). Although intelligence is known to be related to the development of cognitive, linguistic, and mathematics skills (Geary, 1993, 2007; Noël, 2009; Primi, Ferrão, & Almeida, 2010; Stock et al., 2010), recent research suggests that vocabulary is involved in solving many different types of math problems (Foster, Sevcik, Romski, & Morris, 2014; Hooper, Roberts, Sideris, Burchinal, & Zeisel, 2010; LeFevre et al., 2010; Praet, Titeca, Ceulemans, & Desoete, 2013). Evidence also indicates that phonological processing abilities (PPAs) are related to children's early math achievement (Baddeley, 1986; Bull & Johnston, 1997; Clarke & Shinn, 2004; Dehaene, 1992; Dehaene, Piazza, Pinel, & Cohen, 2003; Geary, Hoard, Byrd-Craven, Nugent, & Numtee, 2007; Hecht, Torgesen, Wagner, & Rashotte, 2001; Vukovic, 2012). In the following section, we review these predictors.

Predictors of early math achievement

Vocabulary

Research demonstrates that vocabulary competencies predict later numeracy scores (Praet et al., 2013; Purpura, Hume, Sims, & Lonigan, 2011). In particular, receptive vocabulary is thought to be related to children's ability to acquire vocabulary in the number system (LeFevre et al., 2010), whereas expressive vocabulary helps children to express relationships inherent in mathematical problems (Rothman & Cohen, 1989). Receptive vocabulary refers to the understanding of words (e.g., "big," "more," "three") and word classes (or parts of speech). Expressive vocabulary, however, refers to the bank of words used to communicate when speaking or writing. Given that vocabulary is essential for learning through classroom instruction, children entering into formal education (i.e., kindergarten) with poor vocabulary are likely at a disadvantage when it comes to mathematical and other areas of learning. Children rely on their vocabulary knowledge to help them understand spoken math statements (e.g., "three plus two equals five") and to help them understand written math statements (e.g., $3 + 2 = 5$). With regard to written math statements, children must clearly understand the meaning of Arabic numerals (e.g., 3), operational symbols (e.g., +), and concepts embedded within the