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Working memory and language: Skill-specific or domain-general relations to mathematics?

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A B S T R A C T

Children's early mathematics skills develop in a cumulative fashion; foundational skills form a basis for the acquisition of later skills. However, non-mathematical factors such as working memory and language skills have also been linked to mathematical development at a broad level. Unfortunately, little research has been conducted to evaluate the specific relations of these two non-mathematical factors to individual aspects of early mathematics. Thus, the focus of this study was to determine whether working memory and language were related to only individual aspects of early mathematics or related to many components of early mathematics skills. A total of 199 4- to 6-year-old preschool and kindergarten children were assessed on a battery of early mathematics tasks as well as measures of working memory and language. Results indicated that working memory has a specific relation to only a few—but critically important—early mathematics skills and language has a broad relation to nearly all early mathematics skills.

Introduction

The successful acquisition and development of mathematics skills and concepts is a critical aspect of children's early academic growth (Baroody, Lai, & Mix, 2006; Jordan, Hanich, & Uberti, 2003). Early

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mathematical performance is one of the strongest predictors of later academic and career outcomes (Duncan et al., 2007; Lubinski & Benbow, 2006). Unfortunately, many children fail to achieve early success in mathematics, and these early difficulties tend to persist and become more pronounced over time (Aunola, Leskinen, Lerkkanen, & Nurmi, 2004; Baroody & Ginsburg, 1990). The cumulative nature of early mathematical development—later competencies building on earlier ones—underscores the need for early prevention and intervention with children at risk for developing mathematics difficulties. To effectively intervene in early skills, it is particularly important to understand how these individual skills develop and what factors influence that development. It is evident that a range of both mathematical and non-mathematical factors (e.g., working memory, language) affect children's early mathematical development (Fuchs et al., 2005, 2008, 2010; Gathercole, Pickering, Knight, & Stegmann, 2004; Jarvis & Gathercole, 2003; Purpura, Hume, Sims, & Lonigan, 2011; Raghubar, Barnes, & Hecht, 2010); however, the specificity of the relation between these non-mathematical domains and early mathematics skills is not well understood. The central goal of this study was to identify how these important non-mathematical factors differentially were related to specific early mathematics skills.

Development of early mathematics skills

There is clear evidence that the strongest predictor of *later* mathematics success is *early* mathematical performance (Claessens, Duncan, & Engel, 2009; Duncan et al., 2007; Fuchs et al., 2010). This is because mathematics skills develop as a progression of interrelated facts and concepts (Baroody, 2003; Gersten & Chard, 1999; National Mathematics Advisory Panel [NMAP], 2008; Purpura, Baroody, & Lonigan, 2013) called a learning trajectory (Gravemeijer, 2002; Sarama & Clements, 2009; Simon & Tzur, 2004). Advanced mathematical knowledge is dependent on the acquisition and retention of more basic prerequisites; therefore, missing (or having an underdeveloped ability in) one or more prerequisites limits an individual's ability to acquire the more advanced skills. For example, at the early elementary school level, for a child to successfully (and reliably) acquire fluency in basic arithmetic, the child not only should know the process of adding or subtracting but also must (a) associate specific number word names with the appropriate Arabic numerals (e.g., know that "two" is equal to "2"), (b) associate specific quantities with the appropriate number words and the appropriate Arabic symbols (e.g., know that "•••" is equal to "three" and "3"), and (c) understand the meaning behind operational symbols (e.g., know that "+" means to add). Without developing a strong foundation of these early mathematics skills, children are likely to experience difficulties in acquiring later mathematics skills and be at a higher risk for developing mathematics difficulties than children who do develop a strong foundation of early mathematical knowledge (Baroody & Ginsburg, 1990).

When discussing the early mathematics skills children learn in schools (e.g., basic arithmetic computations), the term *formal* mathematics is typically used. Formal mathematics encompasses those skills and concepts that are taught in school and require the use of abstract written numerical notation such as written arithmetic algorithms using numerals, place-value tasks, knowledge of the base-ten mathematics system, and decimal knowledge (Ginsburg, 1977). However, there are a range of skills called *informal* (or early) mathematics skills that form the basis for the acquisition of formal mathematical knowledge (Bryant, Bryant, Kim, & Gersten, 2006; Chard et al., 2005; Committee on Early Childhood Mathematics, Center for Education, Division of Behavioral & Social Sciences & Education, & National Research Council, 2009; Geary, 1994; Ginsburg, Klein, & Starkey, 1998; Griffin & Case, 1997; Jordan, Kaplan, Ramineni, & Locuniak, 2009; NMAP, 2008;). Informal mathematical knowledge consists of those competencies often learned before or outside of school that typically do not require knowledge of the formal Arabic numeral system (Ginsburg, 1977).

Children's informal mathematics skills are composed of several distinct, but highly related, components (Jordan, Kaplan, Locuniak, & Ramineni, 2007; National Research Council, 2009; Purpura & Lonigan, 2013) that vary in their complexity and difficulty to acquire. These components of informal knowledge are believed to develop in three overlapping phases (Krajewski, 2008; Krajewski & Schneider, 2009). In the first phase, children separately learn to distinguish between small quantities (comparing sets) and learn the verbal counting sequence (number word sequence). In the second phase, they apply the counting sequence to fixed sets (one-to-one counting) and make links between all of the number words and their respective quantities (e.g., they learn to subitize and to apply cardinal