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What counts in preschool number knowledge? A Bayes factor analytic approach toward theoretical model development

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ABSTRACT

Preschool children vary tremendously in their numerical knowledge, and these individual differences strongly predict later mathematics achievement. To better understand the sources of these individual differences, we measured a variety of cognitive and linguistic abilities motivated by previous literature to be important and then analyzed which combination of these variables best explained individual differences in actual number knowledge. Through various data-driven Bayesian model comparison and selection strategies on competing multiple regression models, our analyses identified five variables of unique importance to explaining individual differences in preschool children's symbolic number knowledge: knowledge of the count list, nonverbal approximate numerical ability, working memory, executive conflict processing, and knowledge of letters and words. Furthermore, our analyses revealed that knowledge of the count list, likely a proxy for explicit practice or experience with numbers, and nonverbal approximate numerical ability were much more important to explaining individual differences in number knowledge than general cognitive and language abilities. These findings suggest that children use a diverse set of number-specific, general cognitive, and language abilities to learn about symbolic numbers, but the contribution of number-specific abilities may overshadow that of more general cognitive abilities in the learning process.

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Introduction

Children growing up in industrialized societies begin to acquire a symbolic number system before entering elementary school (Carey, 2009; Gelman & Gallistel, 1978; Wynn, 1990, 1992). This process starts at around 2 years of age, when children start reciting the count list without necessarily understanding the words they are saying, and develops for several more years as children come to understand that each number word in the list represents a unique cardinal value, that the count list can be employed in a counting routine to determine cardinality of any given set of items, and that every number on the count list has a unique successor (Cheung, Rubenson, & Barner, 2017; Fuson, 1988; Gelman & Gallistel, 1978; Le Corre & Carey, 2007; Wynn, 1992). This early preschool symbolic number knowledge appears to lay a foundation for higher mathematics, as it is highly predictive of later mathematical achievement even after controlling for other general cognitive and demographic factors (Jordan, Kaplan, Ramineni, & Locuniak, 2009; Nguyen et al., 2016; vanMarle, Chu, Li, & Geary, 2014). Given its foundational role, it becomes important to know what cognitive and language abilities give rise to individual differences in preschool children's early number knowledge.

Foundations of mathematical thought

A majority of empirical and theoretical work to date has focused on the foundations of later developing mathematical thought. This work suggests that mathematical thinking is generally subserved by at least three components: number-specific, language, and general cognitive abilities (e.g., Cirino, 2011; Dehaene, Piazza, Pinel, & Cohen, 2003; LeFevre et al., 2010). However, the contribution of each component varies with the particular mathematical skill or outcome of interest and across development (e.g., Cirino, 2011; LeFevre et al., 2010; Sowinski et al., 2015). To our knowledge, such theories have yet to be tested at the earliest stages of symbolic numerical concept development in preschoolers. Thus, although these existing theories of the foundations of mathematics provide a general framework for thinking about the types of cognitive and linguistic factors that may be important to thinking about numbers, their particular contributions to initial symbolic number knowledge before children enter school remain unclear.

Sources of individual differences in early number knowledge

Other studies have focused on the foundations of earlier symbolic number knowledge but in a more piecemeal fashion (Abreu-Mendoza, Soto-Alba, & Arias-Trejo, 2013; Brannon & Van de Walle, 2001; Kroesbergen, Van Luit, Van Lieshout, Van Loosbroek, & van de Rijt, 2009; Mussolin, Nys, Content, & Leybaert, 2014; Mussolin, Nys, Leybaert, & Content, 2012; Negen & Sarnecka, 2012; Shusterman, Slusser, Halberda, & Odic, 2016; vanMarle et al., 2014, 2016; Wagner & Johnson, 2011). That is, particular studies have focused on relationships between a particular cognitive or language ability and early symbolic number knowledge.

From this work, knowledge of the count list has been proposed as foundational for conceptual gains in early symbolic number system understanding (e.g., Carey, 2009; Gelman & Gallistel, 1978; Le Corre, Van de Walle, Brannon, & Carey, 2006; Wynn, 1990, 1992). Children start to acquire a symbolic number system by memorizing the number words and their fixed order (i.e., the count list) without necessarily understanding the numerical meanings of the words or knowing how to employ them to count precisely (Carey, 2009; Fuson, 1988; Wynn, 1990, 1992). Furthermore, even after cardinal meanings of the first number words are acquired, knowledge of the count list continues to precede deeper understanding of symbolic number (Carey, 2009; Davidson, Eng, & Barner, 2012; Fuson, 1988; Le Corre et al., 2006). Therefore, although count list knowledge may be a necessary developmental component, it is certainly not sufficient for either conceptual or procedural mastery of the symbolic number system (Carey, 2009; Fuson, 1988; Le Corre et al., 2006). Given its proposed importance, it is not surprising that knowledge of the count list has been shown to correlate with deeper number