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Mathematics and language: Individual and group differences in mathematical language skills in young children

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ABSTRACT

The development of early numeracy knowledge is influenced by a number of non-mathematical factors—particularly language skills. However, much of the focus on the relation between language and early numeracy has utilized general language measures and not domain-specific measures of mathematical language. The primary purpose of this study was to determine if the variance accounted for by general language skills in predicting numeracy performance was better accounted for by mathematical language. Further, age- and parental education-related differences in mathematical language performance were explored. Using a sample of 136 3- to 5-year-old preschool and kindergarten children (M = 4.28 years, SD = 0.67 years), a series of mixed-effect regressions were conducted. Results indicated that although general language performance was initially a significant predictor of numeracy performance, when both mathematical language and general language were included in the model, only mathematical language was a significant predictor of numeracy performance. Further, group-difference analyses revealed that children from families where both parents had less than a college education performed significantly lower on mathematical language than their peers; and even by 3-years-old, children have acquired a substantial body of mathematical language skills. Implications and future directions are discussed.

1. Introduction

Developing early numerical competencies is a complex and continual process that begins even prior to formal schooling (Sarama & Clements, 2009; Starkey, Klein, & Wakeley, 2004). Unfortunately, many children, particularly those from families of low socio-economic-status (SES) struggle to acquire basic numeracy skills and remain behind their peers from families of middle- and high-SES (Jordan, Huttenlocher, & Levine, 1994; Jordan & Levine, 2009; Starkey et al., 2004). It is clear that the developmental process of numeracy skill acquisition does not occur independently from other academic and cognitive skills. For example, LeFevre et al. (2010) identified three specific pathways by which children typically acquire early numeracy knowledge: linguistic (Hooper, Roberts, Sideris, Burchinal, & Zeisel, 2010; Juel, 1988), spatial attention (or executive functioning; McClelland, Acock, & Morrison, 2006), and quantitative (or the approximate number system; Dehaene, 1997; Halberda, Mazzocco, & Feigenson, 2008). These three pathways were based on the three modules identified in Dehaene's triple-code model of number processing (Dehaene, 1992). Although LeFevre et al. noted that each of these pathways uniquely contributes to numeracy knowledge, the linguistic pathway was the most consistent and strongest predictor of early numeracy.

Importantly, the focus of the linguistic pathway is often placed on general language skills/processing (e.g., general vocabulary, phonological awareness), but there is evidence that the language associated with numeracy is highly content-specific (mathematical language; Harmon, Hedrick, & Wood, 2005). However, there is a limited depth of research examining the nature of the language associated with numeracy skills, particularly prior to entry to formal schooling. The central goal in this study was to evaluate individual and group differences in an understudied aspect of the linguistic pathway – children's knowledge of the words utilized in early mathematics, or mathematical language – and the relation of these differences to general numeracy performance.

1.1. The importance of language for numeracy development

The strong relation between numeracy and language is evident relatively early in children's academic development. In preschool

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and early elementary school, children's language skills and numeracy ability are highly related (Hooper et al., 2010; Purpura, Hume, Sims, & Lonigan, 2011; Romano, Babchishin, Pagani, & Kohen, 2010). This relation appears to be general to nearly all aspects of early symbolic numeracy and not specific to individual components of the symbolic system, as Purpura and Ganley (2014) found that language skills accounted for significant variance in predicting nearly all early numeracy skills. However, these connections are presumed to begin even earlier than preschool as substantial evidence indicates that numeracy and language processing activate similar areas of the brain—suggesting they share some common neural pathways (Baldo & Dronkers, 2007; Dehaene, Spelke, Pinel, Stanscu, & Tsivkin, 1999).

Language is the central feature that serves to distinguish the symbolic numeracy system (which typically begins to develop even as young as 18–24 months; Mix, 2009; Sarama & Clements, 2009) from the more primitive non-symbolic approximate quantity discrimination system which is believed to be present beginning in infancy (Dehaene et al., 1999; Spelke & Tsivkin, 2001; Starr, Libertus, & Brannon, 2013; Xu & Spelke, 2000). As children get older, difficulties in numeracy often co-occur with difficulties in literacy and language (Lewis, Hitch, & Walker, 1994; Mann Koepke & Miller, 2013). Those children with difficulties in both areas tend to have more severe (Hanich, Jordan, Kaplan, & Dick, 2001; Jordan & Hanich, 2000) and persistent (Silver, Pennet, Black, Fair, & Balise, 1999) numeracy difficulties than children with numeracy difficulties alone.

Conceptually, numeracy and language are linked in development because language skills are believed to support numerical development (Miura & Okamoto, 2003) as children utilize language skills – particularly number words – to refine their quantitative understanding (Spelke, 2003). Findings from cross-cultural studies suggest that individuals who speak languages that do not have a well-developed counting system are limited in their ability to grasp exact quantities (Gordon, 2004). For example, in languages that have plural markers (e.g., English and Russian), children more readily acquire the concept of "two = ••" than in languages that do not have plural markers (e.g., Chinese and Japanese; Li, Sun, Baroody, & Purpura, 2013; Sarnecka, Kamenskaya, Yamana, Ogura, & Yudovina, 2007). Even within English, children must refine their concepts of quantity through the use of number words. Often, the concept of "one" comes relatively quickly, but the concept of "two" frequently includes anything "more than one" (e.g., •• or ••• are "two" or "not one"; Carey & Sarnecka, 2006; Sarnecka & Lee, 2009; Wynn, 1990, 1992). Over time, children narrow their schema of "two" until it is regularly applied to the quantity "two" (e.g., ••).

1.2. Mathematics-specific language

General language skills – particularly vocabulary – often include words typically heard and used in everyday conversations and activities. However, individual content areas, especially numeracy, have high content-specific vocabulary (Harmon et al., 2005)—words that are primarily used in domain-related contexts or have specific meanings in those contexts. Specifically, there are two general areas of mathematical language terms that are often discussed in relation to early numeracy development: quantitative (Barner, Chow, & Yang, 2009) and spatial (Ramani, Zippert, Schweitzer, & Pan, 2014). Understanding quantitative language (such as "more," "less," "many," and "fewer") allows children to make and describe comparisons between groups or numbers. Understanding spatial language (such as "before," "above," and "near") allows children to talk about relations between physical objects and between numbers on a number line. Essentially, much of the terminology children need to understand and to "do" mathematics is highly language-based. When children do not understand aspects of early mathematical language such as quantifiers (e.g., all, most, some) they also exhibit difficulties in grasping exact mathematical concepts such as cardinal number knowledge (Barner et al., 2009). Further, in elementary school children, mathematical language is a strong predictor of numeracy skills even when accounting for a range of cognitive covariates and prior numeracy achievement (Toll & Van Luit, 2014a). Moreover, knowledge of mathematics-specific language has been surmised to be critical toward the success of early mathematics curricula (Chard et al., 2008; Clements & Sarama, 2011). Even the National Council of Teachers of Mathematics (NCTM, 2006) indicates the importance of high quality mathematics language in teaching:

> *"Children need introductions to the language and conventions of mathematics, at the same time maintaining a connection to their informal knowledge and language. They should hear mathematical language being used in meaningful contexts. . .Young children need to learn words for comparing and for indicating position and direction at the same time they are developing an understanding of counting and number words"* (NCTM, 2006).

Yet, even with the growing body of evidence supporting the importance of mathematical language for numeracy development, it is rarely a focus in early numeracy research. For example, in the LeFevre et al. (2010) pathways model – as is the case in other research connecting numeracy and language skills (Aunio et al., 2006; Krajewski & Schneider, 2009; Purpura et al., 2011) – it is presumed that the linguistic skills directly related to numeracy development are general in nature – measured by components of literacy and language such as vocabulary and/or phonological awareness. Each of those studies included only a measure of general language—and not a mathematical language measure. Further, despite the consistent relation of general language skills to numeracy performance, improving children's general language does not actually result in positive impacts on children's numeracy outcomes (Jordan, Glutting, Dyson, Hassinger-Das, & Irwin, 2012). One of the potential explanations for this finding is that general language skills are acting as a proxy measure for another, more proximal language skill—namely, mathematics-specific language.

1.3. Group differences in mathematical language

An abundance of evidence has indicated that children from families of low-SES perform significantly lower on numeracy (Jordan et al., 1994; Starkey et al., 2004) and language (Hart & Risely, 1995) assessments than their peers from families of middle- and higher-SES. The group differences in numeracy ability are presumed to be, at least in part, due to difficulties in language because of the high language content of early numeracy skills (Jordan et al., 1994; Jordan & Levine, 2009; Starkey et al., 2004). It is estimated that by the time children from families with lower SES enter kindergarten, they have heard, on average, approximately 20–30 million fewer words than their peers from families of higher-SES (Hart & Risely, 1995). Some of the early language in which children and their families engage is mathematical language (Durkin, Shire, Riem, Crowther, & Rutter, 1986; Fuson, 1988). Unfortunately, parents from lower-SES engage in fewer and less complex mathematical interactions with their children than their counterparts from middle- and higher-SES (Saxe, Guberman, & Gearheart, 1987; Vandermaas-Peeler, Nelson, Bumpass, & Sassine, 2009). Thus, children from families of lower-SES are, from very early on, less likely to have had the opportunity to acquire mathematical language skills; yet, no study to date has investigated group differences in children's knowledge of mathematical language words.