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Domain-general mediators of the relation between kindergarten number sense and first-grade mathematics achievement

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ABSTRACT

Domain-general skills that mediate the relation between kindergarten number sense and first-grade mathematics skills were investigated. Participants were 107 children who displayed low number sense in the fall of kindergarten. Controlling for background variables, multiple regression analyses showed that both attention problems and executive functioning were unique predictors of mathematics outcomes. Attention problems were more important for predicting first-grade calculation performance, whereas executive functioning was more important for predicting first-grade performance on applied problems. Moreover, both executive functioning and attention problems were unique partial mediators of the relationship between kindergarten and first-grade mathematics skills. The results provide empirical support for developing interventions that target executive functioning and attention problems in addition to instruction in number skills for kindergartners with initial low number sense.

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Introduction

Proficiency in early number sense is vital to building a foundation for children's later academic success. The preschool and kindergarten number sense "core" encompasses skills related to number, number relations, and number operations and is highly relevant to learning mathematics in elementary school (Jordan, Kaplan, Oláh, & Locuniak, 2006; Malofeeva, Day, Saco, Young, & Ciancio, 2004;

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National Research Council, 2009). Longitudinal research demonstrates that kindergarten and first-grade mathematics skills matter for achievement in later elementary school and beyond (Duncan et al., 2007; Jordan, Glutting, & Ramineni, 2010a; Jordan, Kaplan, Ramineni, & Locuniak, 2009). In the absence of evidenced-based interventions, early weaknesses in number sense often cascade into more severe difficulties (Fuchs, Fuchs, & Compton, 2012; Hart & Risley, 1995; Jordan et al., 2009).

Low-income children typically enter kindergarten with weaknesses in number sense relative to their middle-income peers (e.g., Jordan, Huttenlocher, & Levine, 1994; Jordan et al., 2006). However, children from all socioeconomic backgrounds may begin kindergarten with low number sense; young children do not develop number skills at the same pace, and substantial individual differences can be seen during early childhood (Clements & Sarama, 2009). Some children who enter kindergarten with low number sense catch up to their typically achieving peers through kindergarten instruction, although many others show relatively flat growth trajectories (Jordan et al., 2006). The goal of the current study was to identify potentially malleable domain-general factors that mediate the established relation between children's kindergarten number sense and mathematical achievement in first grade, namely executive functioning and attention problems, for children demonstrating early mathematics difficulties. Such skills might support number learning and help high-risk children to take advantage of early interventions in mathematics (Clark, Sheffield, Wiebe, & Espy, 2013).

Early number sense

It is well known that early facility with numbers plays a key role in learning conventional mathematics. By kindergarten entry, most children can verbally subitize small quantities (i.e., name the cardinal number for small sets of objects immediately without counting) and enumerate sets to at least five. Understanding of one-to-one correspondence and the cardinality principle (Gelman & Gallistel, 1978) helps children to see relationships between and among numbers. Knowing that the next number on a number line is exactly one more than the previous one ($n + 1$) facilitates addition skills (Baroody, Eiland, & Thompson, 2009); children can solve simple arithmetic problems by counting on from a cardinal value. Children's abilities to do simple arithmetic calculations at the beginning of kindergarten are strongly predictive of their later success in mathematics (Jordan et al., 2009). As children build their knowledge of small numbers, they more easily learn to count, compare, and manipulate larger numbers (Jordan, Fuchs, & Dyson, *in press*).

Intervention studies demonstrate the importance of number sense to mathematical learning (Chard et al., 2008). Jordan and colleagues (Dyson, Jordan, & Glutting, 2013; Jordan, Glutting, Dyson, Hassinger-Das, & Irwin, 2012) tested a small group number sense intervention for kindergartners who were not progressing in mathematics by mid-year. The intervention targeted number, number relations, and number operations—all competencies that underlie mathematics difficulties. In a randomized study, it was found that children in the number sense intervention made lasting improvements in mathematics relative to control children (i.e., small group language instruction and business as usual) with moderate to large effect sizes. The intervention children performed better than controls on an immediate posttest as well as several months later.

Executive functioning

Although number sense is a gateway to learning mathematics, weaknesses in domain-general skills related to executive functioning may further constrain children's numerical development (Steele, Karmiloff-Smith, Cornish, & Scerif, 2012). Executive functioning includes processes related to working memory, inhibition and set shifting, and updating for goal-directed activities (Blair, Zelazo, & Greenberg, 2005; Carlson, 2005; Kolkman, Hoijtink, Kroesbergen, & Leseman, 2013; Zelazo, Müller, Frye, & Marcovitch, 2003). Importantly, executive functioning may be malleable. Research has shown that curricula, such as Tools of the Mind, have generated improvements in executive functioning (Barnett et al., 2008). Children's executive functioning skills are closely associated with mathematics performance (Bull & Scerif, 2001; Clark, Pritchard, & Woodward, 2010; Clark et al., 2013; Espy et al.,

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