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Longitudinal mediators of achievement in mathematics and reading in typical and atypical development

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ABSTRACT

Longitudinal studies of neurodevelopmental disorders that are diagnosed at or before birth and are associated with specific learning difficulties at school-age provide one method for investigating developmental precursors of later-emerging academic disabilities. Spina bifida myelomeningocele (SBM) is a neurodevelopmental disorder associated with particular problems in mathematics, in contrast to well-developed word reading. Children with SBM (n = 30) and typically developing children (n = 35) were used to determine whether cognitive abilities measured at 36 and 60 months of age mediated the effect of group on mathematical and reading achievement outcomes at 8.5 and 9.5 years of age. A series of multiple mediator models showed that: visual–spatial working memory at 36 months and phonological awareness at 60 months partially mediated the effect of group on math calculations, phonological awareness partially mediated the effect of group on small addition and subtraction problems on a test of math fluency, and visual–spatial working memory mediated the effect of group on a test of math problem solving. Groups did not differ on word reading, and phonological awareness was the only mediator for reading fluency and reading comprehension. The findings are discussed with reference to theories of mathematical development and disability and with respect to both common and differing cognitive correlates of math and reading.

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Introduction

Neurodevelopmental disorders are often associated with specific patterns of strengths and difficulties in academic achievement. These dissociations in skill development can be useful for understanding the development of academic abilities and disabilities more generally (Mazzocco, Murphy, & McCloskey, 2007). In particular, disorders that are diagnosed before or at birth and for which modal patterns of academic achievement at school-age are known provide the opportunity to use powerful longitudinal designs to examine early developmental precursors of later learning abilities and disabilities. The current study employed a longitudinal multiple mediation design in which children with spina bifida myelomeningocele (SBM) and typically developing children were followed from 36 months to 9 years of age to investigate the overlapping and separate contributions of early cognitive abilities to the later development of mathematics and reading.

SBM is a neurodevelopmental disorder diagnosed before or at birth that affects the development of the spine and brain and is associated with a modal cognitive and academic phenotype at school-age in which word reading is well developed in contrast to deficits in the development of mathematical skills (Ayr, Yeates, & Enrile, 2005; Dennis & Barnes, 2010; Fletcher et al., 2005). Approximately 50% of children with SBM who are not intellectually disabled have math disability (MD; Fletcher et al., 2005). Even when MD is not diagnosed, reading is typically stronger than math (Barnes et al., 2002, 2006). This pattern is found less often in individuals without neurological impairment where there is greater overlap between reading and math skills (Barbaresi, Katusic, Colligan, Weaver, & Jacobsen, 2005; Shalev, Auerbach, Manor, & Gross-Tsur, 2000).

Some of the cognitive predictors of reading and mathematics and growth in these academic domains are similar. Phonological awareness has been related to both reading and math (Hecht, Torgesen, Wagner, & Rashotte, 2001; Krajewski & Schneider, 2009), possibly reflecting the importance of high-quality phonological representations for some aspects of arithmetic such as fact retrieval (De Smedt, Taylor, Archibald, & Ansari, 2010). Weak phonological processing early in life could have implications for early and later mathematical development. Although children with SBM have average or better word decoding skills by school-age, there is some evidence that phonological awareness may show delayed development during the preschool years (Barnes et al., 2011).

Verbal working memory has also been related to performance in both academic domains (Christopher et al., 2012; Raghubar, Barnes, & Hecht, 2010; Swanson & Jerman, 2006; Swanson, Zheng, & Jerman, 2009). In reading verbal working memory is important for assembling speech- and text-based information, and in math it supports encoding, retention, and manipulation of verbal codes used for counting, exact arithmetic, and mathematical algorithms (Dehaene, Piazza, Pinel, & Cohen, 2005). One study found that several aspects of mathematical performance of young children with MD are mediated by working memory, particularly by verbal working memory (Geary, Hoard, Byrd-Craven, Nugent, & Numtee, 2007). Verbal working memory is related to math calculations in adults with SBM (Dennis & Barnes, 2002).

There is also evidence for non-overlapping predictors of growth in reading and mathematics. In studies of typically developing children, visual–spatial working memory may be a unique predictor for mathematics (Bull, Espy, & Wiebe, 2008; Holmes & Adams, 2006; LeFevre et al., 2010). This relation of visual–spatial working memory and math has been linked to the use of visual mental models in math problem solving. In young children, this may involve the manipulation of concrete objects or non-symbolic quantities (Mix, Huttenlocher, & Levine, 2002; Rasmussen, Ho, & Bisanz, 2003). For older children, the use of mental models has been associated with better math word problem solving (Glenberg, Willford, Gibson, Goldberg, & Zhu, 2012) and with performance in domains of math that are typically encountered in the higher elementary and secondary school grades (Holmes, Adams, & Hamilton, 2008; Kyttälä & Lehto, 2008). Deficits in visual–spatial working memory have been found in adults with SBM (Iddon, Morgan, Loveday, Sahakian, & Pickard, 2004), but not in children (Mammarella, Cornoldi, & Donadello, 2003).

Fine motor and finger skills have also been linked uniquely to math in longitudinal studies (Noel, 2005). Some children with math difficulties have finger gnosia that is related to their word problem solving for small magnitudes (i.e., for numbers under 10; Costa et al., 2011), and variability in finger gnosis has been specifically related to the use of fingers during counting and calculation in 5- to 7-