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The predictive value of numerical magnitude comparison for individual differences in mathematics achievement

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ABSTRACT

Although it has been proposed that the ability to compare numerical magnitudes is related to mathematics achievement, it is not clear whether this ability *predicts* individual differences in later mathematics achievement. The current study addressed this question in typically developing children by means of a longitudinal design that examined the relationship between a number comparison task assessed at the start of formal schooling (mean age = 6 years 4 months) and a general mathematics achievement test administered 1 year later. Our findings provide longitudinal evidence that the size of the individual's distance effect, calculated on the basis of reaction times, was *predictively* related to mathematics achievement. Regression analyses showed that this association was independent of age, intellectual ability, and speed of number identification.

Introduction

Understanding individual differences in mathematics achievement represents an important goal in developmental cognitive science. This information is also highly relevant in view of the fact that numerical abilities are crucial to life success in modern Western societies (e.g., Ancker & Kaufman, 2007; Finnie & Meng, 2001). Up until now, research on individual differences in mathematics achievement in typically developing children has focused mainly on the role of domain-general factors such as working memory (e.g., Adams & Hitch, 1997; Bull & Scerif, 2001; Gathercole & Pickering, 2000; Hecht, Torgesen, Wagner, & Rashotte, 2001; Holmes & Adams, 2006; Swanson & Kim, 2007) and processing speed (Bull & Johnston, 1997; Hecht et al., 2001; Kail & Hall, 1999). However, another

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theoretical perspective proposes that the ability to understand and represent numerical magnitudes places important constraints on the development of higher level mathematical skills such as arithmetic (Butterworth, 1999; Dehaene, 1997). In this respect, it has been suggested that the ability to process and compare numerical magnitudes is a key precursor of mathematical development in a similar way as phonological processing is important for reading development (Ansari & Karmiloff-Smith, 2002).

Two recent studies have shown an association between numerical magnitude comparison, which is assumed to measure children's understanding of numerical magnitudes, and mathematics achievement (Durand, Hulme, Larkin, & Snowling, 2005; Holloway & Ansari, in press). Both studies were, however, cross-sectional in nature. On the basis of such data, it is not clear whether individual differences in numerical magnitude comparison *predict* later individual differences in mathematics. To the best of our knowledge, there are currently no studies that have examined this relationship longitudinally. Therefore, the current investigation tried to extend the available cross-sectional studies by means of a longitudinal design that examined the association between number comparison at the start of formal schooling (i.e., at the start of first grade) and mathematics achievement 1 year later. Because the latter assessment of number comparison is not influenced by formal mathematics education in primary school, it allows us to examine whether individual differences in the ability to compare numbers can predict subsequent mathematics achievement. In the remainder of this introduction, we review the available evidence for the hypothesis that the ability to understand numerical magnitudes is related to individual differences in mathematics and present the specific aims of our study.

There are several arguments for the claim that the ability to understand and represent numerical magnitudes is related to the development of mathematics. First of all, there are theoretical arguments for assuming such a relationship. For example, Booth and Siegler (2008) argued that a good understanding of numerical magnitudes narrows the range of candidate answers when arithmetic problems are presented, leading to increasingly accurate performance or to errors that are close misses. Such knowledge also allows children to check the plausibility of their answers on the basis of the numbers' magnitudes. Furthermore, this understanding of numerical magnitudes might aid children's early arithmetical development. For example, when children start learning to solve arithmetic problems, they use counting procedures (e.g., Geary, Bow-Thomas, & Yao, 1992; Siegler, 1996). Initially, children count both addends to find the solution. Gradually, development shifts toward a more advanced counting procedure, the so-called *min* procedure or counting-from-larger strategy. This involves stating the larger valued addend and then counting the number of times equal to the value of the smaller valued addend, for example, counting 8, ... 9, 10 to solve 2 + 8. This procedure requires the child to make a decision on the larger addend, which draws on understanding of numerical magnitudes.

Second, cognitive neuroimaging studies have shown systematically that the intraparietal sulcus, which is dedicated to the processing of magnitudes in children (Ansari et al., 2005; Kaufmann et al., 2008; Temple & Posner, 1998) and adults (for a review, see Ansari, 2008; Dehaene, Piazza, Pinel, & Cohen, 2003), appears to be consistently active during arithmetical tasks (Dehaene et al., 2003; Rivera, Reiss, Eckert, & Menon, 2005; Stanescu-Cosson et al., 2000). Thus, there is also neural evidence to suggest that the processing of numerical magnitudes is important for higher level mathematical tasks such as arithmetic. In addition, neuroimaging studies in children with mathematical disabilities have shown that these children have structural abnormalities (Barnea-Goraly et al., 2005; Isaacs, Edmonds, Lucas, & Gadian, 2001; Rotzer et al., 2008) and functional abnormalities (Price et al., 2007) in those areas of the brain that are dedicated to the processing of numerical magnitudes.

Third, the behavioral evidence for a relationship between the understanding and processing of numerical magnitudes and mathematics achievement initially came from studies on children with mathematical disabilities or developmental dyscalculia. These studies showed that children with mathematical disabilities have particular deficits in the understanding and processing of numerical magnitudes (Geary, Hoard, Nugent, & Byrd-Craven, 2008; Landerl, Bevan, & Butterworth, 2004; Rousselle & Noël, 2007; Simon, Bearden, McDonald-McGinn, & Zackai, 2005; Simon et al., 2008). De Smedt et al. (2009) recently showed that these impairments in representing numerical magnitudes were directly related to poor performance and strategy use in single-digit arithmetic. However, that study was cross-sectional in nature, and it remains unclear whether the impairments in representing numerical magnitudes are the source or the consequence of impairments in single-digit arithmetic.