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Differential processing of symbolic numerical magnitude and order in first-grade children

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ABSTRACT

A growing body of evidence has indicated a link between individual differences in children's symbolic numerical magnitude discrimination (e.g., judging which of two numbers is numerically larger) and their arithmetic achievement. In contrast, relatively little is known about the processing of numerical order (e.g., deciding whether two numbers are in ascending or descending numerical order) and whether individual differences in judging numerical order are related to the processing of numerical magnitude and arithmetic achievement. In view of this, we investigated the relationships among symbolic numerical magnitude comparison, symbolic order judgments, and mathematical achievement. Data were collected from a group of 61 first-grade children who completed a magnitude comparison task, an order judgment task, and two standardized tests of arithmetic achievement. Results indicated a numerical distance effect (NDE) in both the symbolic numerical magnitude discrimination and the numerical order judgment condition. However, correlation analyses demonstrated that although individual differences in magnitude comparison correlated significantly with arithmetic achievement, performance on the order judgment task did not. Moreover, the NDE of the magnitude and order comparison performance was also found to be uncorrelated. These findings suggest that order and numerical magnitude processing may be underpinned by different processes and relate differentially to arithmetic achievement in young children.

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Introduction

We constantly process numerical information in a symbolic format in everyday life (Butterworth, 1999). Number symbols are abstract representations of numerical magnitudes (i.e., the total number of items in a set). Much attention has been paid to how we process the numerical magnitude represented by symbols (e.g., Ansari, 2008; Holloway, Battista, Vogel, & Ansari, 2012; Holloway, Price, & Ansari, 2010; Nieder & Dehaene, 2009; Vogel, Grabner, Schneider, Siegler, & Ansari, 2013) and how symbolic numerical magnitude processing develops and relates to individual differences in mathematical achievement (e.g., Bugden & Ansari, 2010; De Smedt, Verschaffel, & Ghesquière, 2009; Holloway & Ansari, 2009).

However, numerical symbols do not only represent numerical magnitude. Every numeral is part of a sequence and, therefore, conveys information about its relative position within a sequential order. An understanding of the ordinal relationships between number symbols has been hypothesized as essential for efficient symbolic number processing (Butterworth, 1999). For example, the Arabic digit 4, depending on the context, might not solely relate to the numerical magnitude of 4 apples carried in a shopping bag but might also represent the 4th position of a runner in a marathon, thereby conveying ordinal information. In other words, symbolic numerical knowledge is not merely characterized by *symbol–quantity relationships* (i.e., the mapping of a symbol to the magnitude it represents) but also characterized by *symbol–symbol relationships* (i.e., understanding the symbol as part of an ordered sequence, similar to the alphabet that does not possess a symbol–quantity mapping). In numerical order, no explicit access to quantity meaning is necessary to judge the position of a given numeral within a number sequence. Hence, symbol–symbol relationships may suffice for judgments of numerical order.

In the current literature, there has been a predominant focus on the processing of relative numerical magnitude conveyed by numerical symbols such as the Arabic numerals. Experimental studies, designed to index symbolic numerical magnitude processing, have indeed been very successful in identifying cognitive mechanisms that may underlie the processing of symbolic numerical magnitude. For instance, the numerical distance effect (NDE), an inverse relationship between reaction time and the numerical distance (the numerical difference between two numbers) of two compared numerals, has been argued to index an internal analog representation in which numerical magnitudes are represented as approximate quantities along a hypothetical mental number line (Moyer & Landauer, 1967). Furthermore, the magnitude of the NDE has been found to undergo age-related changes that have been interpreted as a developmental refinement in the processing of symbolic numerical magnitudes (Holloway & Ansari, 2008, 2009; Sekuler & Mierkiewicz, 1977).

Moreover, it has been shown that individual differences in the magnitude of the NDE relate to measures of arithmetic achievement. Specifically, several studies have reported reliable correlations between individual differences in children's ability to discriminate symbolic numerical magnitudes and between-participant variability in arithmetic achievement (Bugden & Ansari, 2010; De Smedt et al., 2009; Holloway & Ansari, 2009; Mundy & Gilmore, 2009; Sasanguie, De Smedt, Defever, & Reynvoet, 2012; Sasanguie, Van den Bussche, & Reynvoet, 2012). For instance, Holloway and Ansari (2009) collected reaction time data from 6- to 8-year-old children who performed a numerical comparison task and standardized tests of mathematical achievement. A significant correlation between individual differences in the size of the NDE and children's standardized test scores of mathematical fluency was found. In other words, children with a relative small NDE scored significantly better in the mathematical achievement test, suggesting a link between symbolic numerical magnitude representation and mathematical performance. In addition to these findings, there is also increasing evidence for an association between individual differences in the performance of non-symbolic magnitude comparison tasks, such as deciding which of two dot arrays contains the larger number of dots, and individual differences in mathematical achievement. This indicates a possible early link between non-symbolic magnitude representation and mathematical performance (Feigenson, Libertus, & Halberda, 2013; Halberda, Mazzocco, & Feigenson, 2008; Libertus, Feigenson, & Halberda, 2011; Libertus, Odic, & Halberda, 2012). However, the precise relationship among non-symbolic magnitude, symbolic numerical magnitude representation, and mathematical achievement remains opaque, as