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Longitudinal development of number line estimation and mathematics performance in primary school children

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ABSTRACT

Children's ability to relate number to a continuous quantity abstraction visualized as a number line is widely accepted to be predictive of mathematics achievement. However, a debate has emerged with respect to how children's placements are distributed on this number line across development. In the current study, different models were applied to children's longitudinal number placement data to get more insight into the development of number line representations in kindergarten and early primary school years. In addition, longitudinal developmental relations between number line placements and mathematical achievement, measured with a national test of mathematics, were investigated using cross-lagged panel modeling. A group of 442 children participated in a 3-year longitudinal study (ages 5–8 years) in which they completed a number-to-position task every 6 months. Individual number line placements were fitted to various models, of which a one-anchor power model provided the best fit for many of the placements at a younger age (5 or 6 years) and a two-anchor power model provided better fit for many of the children at an older age (7 or 8 years). The number of children who made linear placements

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also grew with age. Cross-lagged panel analyses indicated that the best fit was provided with a model in which number line acuity and mathematics performance were mutually predictive of each other rather than models in which one ability predicted the other in a non-reciprocal way. This indicates that number line acuity should not be seen as a predictor of math but that both skills influence each other during the developmental process.

Introduction

Will I need to run to be in time for school? If my brother gets three pieces of candy and I get two, is that fair? To answer these questions, one needs an understanding of number, often referred to as number sense, which is children's ability to intuitively understand and relate numbers (Dehaene, 2001). Number sense is considered to be a precursor to formal understanding of mathematics (De Hevia & Spelke, 2009; Dehaene, 2001) and, therefore, of vital importance for later school success.

Recent insights into the development of number sense suggest that children develop an understanding of number, quantity, and relations between numbers at a young age. Although different studies may differ in their definition of number sense and involved skills or abilities, the cognitive tool most often associated with number sense is the mental number line (Dehaene, 1992; Dehaene, Bossini, & Giraux, 1993; Feigenson, Dehaene, & Spelke, 2004; Verguts & Fias, 2004). On this assumed mental number line, numbers are ordered in accordance with their magnitude, and comparisons between numbers can be made by mentally estimating the location of numbers on the number line (Laski & Siegler, 2007). Number line representations are typically investigated using the number-to-position task (Siegler & Opfer, 2003). In this task, children are shown a blank number line with the beginning and end points marked with numbers (e.g., 0 and 100) and are asked to indicate the position of a certain number on this line by drawing a hatch mark on the location or pointing to the intended location. Number line acuity is thought to be associated with number sense at an early age (e.g., Dehaene, 2001), but in this study it was assumed to be more dependent on strategy use and taught facts after the onset of formal education. In the current study, longitudinal development of number line placements and its relation to mathematics performance was investigated.

Changes in numerical abilities across developmental time can also be indexed with the number-to-position task. As children get older, their estimations of numbers on the number line become increasingly accurate (e.g., Ebersbach, Luwel, Frick, Onghena, & Verschaffel, 2008; Friso-van den Bos, Kolkman, Kroesbergen, & Leseman, 2014; Laski & Siegler, 2007). Accuracy of number line placements increases because children learn to consistently place larger numbers on the right side of the number line (Friso-van den Bos et al., 2014) and because children's ability to determine the spatial distance between placements improves, meaning that they learn to understand that the distance between 10 and 20 on the number line is equal to the distance between 80 and 90 (Laski & Siegler, 2007). These two forms of improvement result in more linear associations between the placements on the number line and the actual numerical values. Linear and accurate placements of numbers on a number line have been shown to be associated with higher mathematics achievement (Geary, 2011; Halberda, Mazzocco, & Feigenson, 2008; Sasanguie, De Smedt, Defever, & Reynvoet, 2012; Sasanguie, Göbel, Moll, Smets, & Reynvoet, 2013; Siegler & Booth, 2004). Therefore, the literature highlights the importance of linear and accurate placements for the development of mathematical achievement.

Models of number line placement

Whereas it has widely been acknowledged that young children's number line placements do not yet follow a perfectly linear pattern (e.g., Geary, 2011; Halberda et al., 2008; Sasanguie et al., 2013;