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Development of numerical estimation in Chinese preschool children

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ABSTRACT

Although much is known about the development of mental representations of numbers, it is not clear how early children begin to represent numbers on a linear scale. The current study aimed to examine the development of numerical estimation of Chinese preschoolers. In total, 160 children of three age groups (51 3- and 4-year-olds, 50 5-year-olds, and 59 6-year-olds) were administered the numerical estimation task on three types of number lines (Arabic numbers, dots, and objects). All three age groups took the test on the 0–10 number lines, and the oldest group also took it on the 0–100 and 0–1000 Arabic number lines. Results showed that (a) linear representation of numbers increased with age, (b) representation of numbers was consistent across the three types of tasks, (c) Chinese participants generally showed earlier onset of various landmarks of attaining linear representations (e.g., linearity of various number ranges, accuracy, intercepts) than did their Western counterparts, as reported in previous studies, and (d) the estimates of older Chinese preschoolers on the 0–100 and 0–1000 symbolic number lines fitted the two-linear and linear models better than alternative models such as the one-cycle, two-cycle, and logarithmic models. These results extend the small but accumulating literature on the earlier development of number cognition among Chinese preschoolers compared with their Western counterparts, suggesting the importance of cultural factors in the development of early number cognition.

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Introduction

Researchers have long been interested in mental representations of numbers and their development because such representations play an important role in mathematical cognition. To study mental representations, investigators have relied on Fechner's law that the magnitude of a sensation is a logarithmic function of objective stimulus intensity. This law is believed to describe representations of numerical as well as physical magnitudes (Bank & Hill, 1974; Dehaene, 1997). One of the widely used tasks to examine how the human mind represents numbers is the number line estimation task, in which participants are asked to place a given number on a straight line anchored with numbers at the two ends (e.g., 0 on the left end and 10 or 100 on the right end; Barth & Paladino, 2011; Dehaene, Izard, Spelke, & Pica, 2008; Ebersbach, Luwel, Frick, Onghena, & Verschaffel, 2008; Geary, Hoard, Nugent, & Byrd-Craven, 2008; Moeller, Pixner, Kaufmann, & Nuerk, 2009; Muldoon, Simms, Towse, Menzies, & Yue, 2011; Opfer, Siegler, & Young, 2011; Siegler & Booth, 2004; Siegler & Opfer, 2003; Slusser, Santiago, & Barth, 2013; Whyte & Bull, 2008; Young & Opfer, 2011).

Empirical data from the number line estimation task have led researchers to propose several models of mental representations of numbers. For example, to explain the distance effect that was observed with infants and animals (Dehaene, Dehaene-Lambertz, & Cohen, 1998; Starkey & Cooper, 1980), Dehaene (1997) proposed the *logarithmic model*, which suggests that infants exaggerate the distance between the small numbers and minimize the distance between the middle and large numbers. As an extreme case, Dehaene and his colleagues (2008) even found evidence of such a model in adults. The Mnundurucu people (adults as well as children) in the Amazon showed logarithmic representation of numbers on the 0–10 number line estimation task. This was true for both symbolic and nonsymbolic number lines. Because the Mnundurucu people have no structured mathematical language or formal schooling, the above results seem to further support the idea that logarithmic representation is the initial and intuitive way of mapping numbers to space. For Western children, however, this intuitive logarithmic representation is replaced by a linear representation at around 6 years of age (Case & Okamoto, 1996).

The strongest support for the *logarithmic-to-linear shift* hypothesis came from a large number of developmental studies carried out by Siegler and his colleagues (Booth & Siegler, 2006, 2008; Laski & Siegler, 2007; Opfer & Siegler, 2007; Opfer & Thompson, 2008; Opfer et al., 2011; Ramani & Siegler, 2008; Siegler & Booth, 2004; Siegler & Mu, 2008; Siegler & Opfer, 2003; Siegler & Ramani, 2008, 2009; Young & Opfer, 2011). They identified different ages at which American children move away from logarithmic representations and develop linear representations of different ranges of numbers. Specifically, they found that linearity in the 0–10 range was attained by preschoolers (at least for those who came from a middle-class background), that linearity in the 0–100 range was attained by some first graders and most second graders, and that linearity in the 0–1000 range was attained by some fourth and fifth graders and most sixth graders.[1]

During the past few years, researchers have also proposed alternative models of number representation. For example, Ebersbach and colleagues (2008) showed that a segmented linear regression model outperformed the logarithmic model to explain the performance of 5- to 9-year-old children on the 0–100 number line task. They further found that the breakpoint between the two linear segments of the model was associated with children's familiarity with numbers as assessed by a counting task. Similar to Ebersbach's model, but based on the decomposed representations of tens and units in two-digit number processing (Nuerk, Kaufmann, Zoppoth, & Willmes, 2004; Nuerk, Weger, & Willmes, 2001; Nuerk & Willmes, 2005; Wood, Nuerk, & Willmes, 2006), Moeller and colleagues (2009) proposed a *two-linear model* with the breakpoint between single- and two-digit numbers. They found evidence to support the two-linear model for first graders on the 0–100 number line task.

[1] Siegler and colleagues studies also included control tasks such as a color board game, a circular board game task, and a numerical activity task because they were intervention studies. The control tasks typically showed much poorer indexes of linear representations at both the group and individual levels and both before and after the intervention (see Ramani & Siegler, 2008; Siegler & Ramani, 2009, for details).