Journal of Experimental Child Psychology 117 (2014) 29–44

Contents lists available at ScienceDirect

Journal of Experimental Child Psychology

journal homepage: www.elsevier.com/locate/jecp

Number line estimation and mental addition: Examining the potential roles of language and education

Elida V. Laski *, Qingyi Yu

Department of Applied Developmental and Educational Psychology, Lynch School of Education, Boston College, Chestnut Hill, MA 02467, USA

ARTICLE INFO

Article history:
Received 25 January 2013
Revised 13 August 2013
Available online 15 October 2013

Keywords:
Mathematics
Arithmetic
Number line estimation
Cross-cultural
Numerical

ABSTRACT

This study investigated the relative importance of language and education to the development of numerical knowledge. Consistent with previous research suggesting that counting systems that transparently reflect the base-10 system facilitate an understanding of numerical concepts, Chinese and Chinese American kindergartners' and second graders' number line estimation (0–100 and 0–1000) was 1 to 2 years more advanced than that of American children tested in previous studies. However, Chinese children performed better than their Chinese American peers, who were fluent in Chinese but had been educated in America, at kindergarten on 0–100 number lines, at second grade on 0–1000 number lines, and at both time points on complex addition problems. Overall, the pattern of findings suggests that educational approach may have a greater influence on numerical development than the linguistic structure of the counting system. The findings also demonstrate that, despite generating accurate estimates of numerical magnitude on 0–100 number lines earlier, it still takes Chinese children approximately 2 years to demonstrate accurate estimates on 0–1000 number lines, which raises questions about how to promote the mapping of knowledge across numerical scales.

Introduction

Although a range of species possess an approximate representation of numerical magnitude that allows them to reason about the magnitude of nonsymbolic quantities, only humans are able to

* Corresponding author. Fax: +1 617 552 1981.
E-mail address: laski@bc.edu (E.V. Laski).

http://dx.doi.org/10.1016/j.jecp.2013.08.007

precisely represent and operate on the magnitude of symbolic numerals (Cantlon, Platt, & Brannon, 2009; Feigenson, Dehaene, & Spelke, 2004). With development, humans become increasingly accurate at representing the magnitudes of large numbers (Barth & Paladino, 2011; Berteletti, Lucangeli, Piazza, Dehaene, & Zorzi, 2010; Ebersbach, Luwel, Frick, Onghena, & Verschaffel, 2008; Holloway & Ansari, 2008; Laski & Siegler, 2007; Siegler & Booth, 2004). This uniquely human ability and developmental trajectory is thought to be influenced by cultural practices, including language, the writing system, and formal education (Göbel, Shaki, & Fischer, 2011; Ho & Cheng, 1997; Ng & Rao, 2010; Towse & Saxton, 1998). This study investigated the relative importance of the structure of language and education to the development of accurate numerical estimates in large number ranges (0–100 and 0–1000) and exact mental calculation of sums in the same numerical ranges.

Understanding whether certain factors have a greater influence than others in the early development of numerical knowledge is important for identifying approaches for improving mathematics achievement. Children with more accurate numerical magnitude representations in the first grade show faster growth in math skills over the elementary school years even after controlling for alternative predictive factors such as intelligence and working memory (Geary, 2011). Furthermore, among both Western and Asian children, more accurate magnitude representations are associated with better performance on general number problems (Muldoon, Simms, Towse, Menzies, & Yue, 2011). If certain factors are found to be particularly important for early development of numerical magnitude knowledge, then they could be leveraged to improve children's mathematics achievement trajectory.

Language and numerical thinking

Language allows humans to count and name even very large quantities; thereby, it serves as a tool in the formation of exact mental representations of large numerical quantities and in mental operations on those representations. Evidence of this function of language has been found by examining the numerical understandings of young children who have not yet fully developed language as well as adults with limited linguistic systems for counting. Children and adults exhibit better understanding of numerical magnitude and greater accuracy on exact calculation tasks when they possess language words for the numerical range involved (Dehaene, Izard, Spelke, & Pica, 2008; Pica, Lemer, Izard, & Dehaene, 2004).

The linguistic structure of the counting system might also facilitate or impede numerical development. Languages differ in the extent to which they communicate features about number such as the base-10 system. In Chinese and other Asian languages, multi-digit numbers are expressed by consistent rules for combining the primary numbers (e.g., 12 is "ten-two") that transparently reflect the base-10 system. In contrast, English and other Western languages use inconsistent rules and arbitrary number words to express teens and other multi-digit numbers (e.g., 12 is "twelve"). This difference in the structure of counting systems has been associated with early numerical development in the areas of counting (Miller & Stigler, 1987; Song & Ginsburg, 1988), single-digit and multi-digit mental arithmetic (Dowker, Bala, & Lloyd, 2008; Geary, Bow-Thomas, Liu, & Siegler, 1996), place value understanding (Fuson, 1992), and the precision of numerical estimation (Helmreich et al., 2011; Siegler & Mu, 2008). Individuals from cultures with transparent counting systems consistently outperform those from cultures with less transparent systems in these aspects of numerical thinking.

The advantage in numerical thinking associated with languages with transparent counting systems seems to be independent of formal education. One indication of this dissociation is that the advantage emerges even before formal education (Miller & Stigler, 1987; Paik, van Gelderen, Gonzales, de Jong, & Hayes, 2011). For example, even before formal education, Chinese kindergartners generate estimates that increase linearly with the magnitude of the numbers presented for numbers between 0 and 100 on a number line estimation task, whereas their American peers generate estimates that increase logarithmically (Siegler & Mu, 2008). Another indication is that this advantage is also present in adults with different language backgrounds but similar levels of education (Campbell & Xue, 2001; Imbo & LeFevre, 2008).

Despite this strong evidence in favor of language's contribution to numerical knowledge, there are also findings that suggest it might not influence children's understanding of numerical magnitude. Consider German children's performance on a number line estimation task. The linguistic counting