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Reexamining the language account of cross-national differences in base-10 number representations

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ABSTRACT

East Asian students consistently outperform students from other nations in mathematics. One explanation for this advantage is a language account; East Asian languages, unlike most Western languages, provide cues about the base-10 structure of multi-digit numbers, facilitating the development of base-10 number representations. To test this view, the current study examined how kindergartners represented two-digit numbers using single unit-blocks and ten-blocks. The participants ($N = 272$) were from four language groups (Korean, Mandarin, English, and Russian) that vary in the extent of "transparency" of the base-10 structure. In contrast to previous findings with older children, kindergartners showed no cross-language variability in the frequency of producing base-10 representations. Furthermore, they showed a pattern of within-language variability that was not consistent with the language account and was likely attributable to experiential factors. These findings suggest that language might not play as critical a role in the development of base-10 representations as suggested in earlier research.

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Introduction

Cross-national studies reveal persistent differences in mathematics; American school students are outperformed by counterparts from some Asian and European countries, including those with fewer educational resources (Gonzales, Williams, Jocelyn, Roey, Kastberg, & Brenwald, 2008; Mullis, Martin, Foy, & Arora, 2012; Stevenson, Chen, & Lee, 1993). For example, the latest large-scale mathematics assessment showed that eighth graders from South Korea and Russia scored higher than their American peers even though the United States spends twice as much money per pupil as South Korea and nearly four times as much as Russia (Mullis et al., 2012). Understanding the sources of these differences is critical to America's ability to compete during a time of accelerating progress in science and technology.

Although a variety of factors, including parental values and instructional approaches, have been identified as potential sources of such differences (cf. Göbel, Shaki, & Fischer, 2011; Ng & Rao, 2010), the role of language has become a prominent account in psychological and popular literature discussing cross-national differences in mathematics (Gladwell, 2008; Krulwich, 2011). Based on this account, the roots of Asian students' mathematics advantage can be traced to the period of development when children acquire basic linguistic and conceptual knowledge of numbers prior to extensive exposure to formal schooling. The current study offers new evidence about the extent to which linguistic factors may account for differences in foundational mathematics concepts, particularly children's understanding of the base-10 structure of numbers.

The language account

Acquiring numeric language plays a significant role in the development of mathematical thinking. For example, language provides a means of forming exact representations of large quantities (Dehaene, Izard, Spelke, & Pica, 2008). It has been further suggested that the linguistic structure of counting systems might facilitate or impede numerical development. Specifically, several Asian languages use number naming systems that can be characterized as "transparent," whereby the names of multi-digit numbers explicitly reflect their base-10 structure. For example, the Chinese word for 12 is "ten-two," the word for 34 is "three-ten four," and so forth. Conversely, English does not provide equally transparent information about the base-10 structure. In fact, the first two-digit numbers that English-speaking children learn, "eleven" and "twelve," have arbitrary labels with no clues about number composition. Words beyond 12 are organized more systematically, but phonetic modifications complicate the extraction of the tens and ones. Such linguistic differences may lead to differences in numeric thinking. In particular, children's mental representation of numbers might vary as a function of support available for the base-10 structure in their language (Helmreich, Zuber, Pixner, Kaufmann, Nuerk, & Moeller, 2011).

Early empirical evidence for this idea came from studies examining performance on a number representation block task (Miura, 1987; Miura, Kim, Chang, & Okamoto, 1988). In this task, children needed to show two-digit numbers using blocks that included small cubes representing single units and bars representing ten units. Asian first graders tended to produce base-10 representations (combinations of ten-bars and single units), whereas American first graders tended to use only single-unit cubes to represent the same numbers. For example, when shown the number 34, Japanese children typically represented it with three ten-bars and four single units, whereas American children used 34 single units (Miura & Okamoto, 1989).

In addition to findings implicating the transparency of counting words in children's understanding of the base-10 number structure, it has been suggested that language may, in part, account for cross-national variability in other math skills. For instance, researchers have shown that children with different linguistic systems demonstrate differences in counting skills (Miller & Stigler, 1987; Song & Ginsburg, 1988), mental arithmetic (Dowker, Bala, & Lloyd, 2008; Geary, Bow-Thomas, Liu, & Siegler, 1996), place-value understanding (Fuson, 1992), and numerical estimation (Laski & Yu, 2014; Siegler & Mu, 2008). In this literature, investigators discuss how diverse aspects of language, including the length of the count words, the number of unique count words that must be learned, and the transparency of multi-digit numbers, might influence mathematical learning.

In the current study, we were interested specifically in the relationship between the transparency of the number system and children's representation of the base-10 number structure. Cross-national