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Observation of directional storybook reading influences young children's counting direction

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ABSTRACT

Even before formal schooling, children map numbers onto space in a directional manner. The origin of this preliterate spatial–numerical association is still debated. We investigated the role of enculturation for shaping the directionality of the association between numbers and space, focusing on counting behavior in 3- to 5-year-old preliterate children. Two studies provide evidence that, after observing reading from storybooks (left-to-right or right-to-left reading) children change their counting direction in line with the direction of observed reading. Just observing visuospatial directional movements had no such effect on counting direction. Complementarily, we document that book illustrations, prevalent in children's cultures, exhibit directionality that conforms to the direction of a culture's written language. We propose that shared book reading activates spatiotemporal representations of order in young children, which in turn affect their spatial representation of numbers.

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Introduction

Cultural differences reflect and reinforce behavioral practices, from social conventions to traffic directions (Berry, Breugelmans, Poortinga, Chasiotis, & Sam, 2011). Our cognitive skills are also shaped

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by cultural practices, as in the systematic use of physical space for literacy and numeracy. When asked to think about numbers, people often activate a mental number line on which number concepts are represented by increasing magnitude and with systematic direction: In Western cultures, small numbers are associated with left space and larger numbers with right space. Spontaneous associations between number and space were initially described in Western adults (Dehaene, Bossini, & Giraux, 1993; Göbel, Shaki, & Fischer, 2011; Shaki, Fischer, & Göbel, 2012; Wood, Willmes, Nuerk, & Fischer, 2008) and children (Berch, Foley, Hill, & Ryan, 1999; Hoffmann, Hornung, Martin, & Schiltz, 2013). These associations were initially attributed to a "spillover" from habitual reading direction (Berch et al., 1999; Dehaene et al., 1993). However, the presence of such an association between numbers and space already in preschoolers who are not yet reading fluently (Opfer, Thompson, & Furlong, 2010; Patro & Haman, 2012; Shaki et al., 2012) demands a different explanation for its origin. The current article provides evidence for a novel account that explains the directional nature of this early-developing association between numbers and space in preschoolers and how it differs across cultures.

A general preference for an association between numbers of increasing magnitude and left-to-right space has been found in both preverbal infants (Bulf, de Hevia, & Macchi Cassia, 2016; de Hevia, Girelli, Addabbo, & Macchi Cassia, 2014) and nonhuman animals (Adachi, 2014; Rugani, Kelly, Szelest, Regolin, & Vallortigara, 2010; Rugani, Vallortigara, Priftis, & Regolin, 2015). For example, Bulf et al. (2016) showed that centrally presented numerosities bias the visual attention of 8- and 9-month-olds in a directional manner. This shifting of spatial attention was specific for numerical cues and not present for non-numerical cues (small/large shapes). Rugani et al. (2015) reported that 3-day-old chicks trained with an intermediate number of dots subsequently spontaneously associated a smaller numerosity with the left side and a larger numerosity with the right side of space (but see Shaki & Fischer, 2015). This suggests a biological contribution to the association between numerical magnitudes and space that is at some point modified by culture.

In humans, the direction of the association between number and space is influenced by how long adults had lived in a left-to-right reading culture (Dehaene et al., 1993; Shaki, Fischer, & Petrusic, 2009). This cultural modulation is also present in other numerical tasks such as counting; whereas the majority of British adults count horizontally aligned objects from left to right, most Arab adults—in line with their predominant reading direction—count them from right to left (Shaki et al., 2012). This cultural contribution has often been explained as reflecting the many hours spent actively scanning text with eyes and fingers (Shaki & Fischer, 2008). Specifically, making repeated horizontal eye movements, often accompanied by directional finger movements, might induce a directional bias in line with the acquired, culturally predominant reading direction. However, the presence of a similar association between numbers and space already in preliterate children requires a modification of this proposed mechanism. An early biologically driven preference to associate small numerosities with left space might be subsequently shaped by cultural (spatial) experiences such as reading (Bulf et al., 2016; de Hevia et al., 2014; Nuerk et al., 2015). This explanation is appealing and covers the majority of available findings. However, it does not explain exactly *how* cultural experience works to alter the association between numbers and space at such a young age.

Here we tested the role of another cultural experience in the emergence of culture-specific spatial–numerical associations—parents and children reading together. Although preliterate children cannot read, they experience reading-related activities. They monitor adult reading behavior (Dobel, Diesendruck, & Bölte, 2007), pretend to read or write (Sulzby, 1985; Tolchinsky, 2003), and often possess some rudimentary writing skills (Puranik, Lonigan, & Kim, 2011). Storybook reading is a pervasive activity in the homes, preschools, and day-care centers of literate societies. Surveys in the United States (Montag, Jones, & Smith, 2015; Raikes et al., 2006) suggest that 30–50% of parents of preliterate children read to their children at least once a day. Even children who do not fully understand reading can be found happily paging through a book (Sulzby, 1985). Thus, both the spatial characteristics of printed materials and the observations of others interacting with such materials are likely influences on the development of the association between numbers and space in preliterate children. This cluster of activities surrounding reading—referred to as *reading observation*—might shape the direction of an early association between numbers and space. The current studies tested this hypothesis.

Reading observation is beginning to receive attention as a likely mechanism shaping the association between numbers and space in preliterate children (McCrink, Caldera, & Shaki, 2017; McCrink

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