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Brief Report

The spatial–numerical congruity effect in preschoolers

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A R T I C L E I N F O

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A B S T R A C T

Number-to-space mapping and its directionality are compelling topics in the study of numerical cognition. Usually, literacy and math education are thought to shape a left-to-right number line. We challenged this claim by analyzing performance of preliterate precounting preschoolers in a spatial–numerical task. In our experiment, children exhibited a spatial–numerical congruity (SNC) effect during a nonsymbolic numerosity comparison (quicker reaction times to smaller sets presented on the left side of the screen and to larger ones presented on the right side). These findings suggest that left-to-right number ordering may also have some sources that are independent of reading and math education. We argue that the current explanations of the spatial–numerical link need to be reconsidered.

Introduction

The problem of the relation between number and space representations reveals several interesting issues in numerical cognition (for reviews, see Hubbard, Piazza, Pinel, & Dehaene, 2005; Wood, Willmes, Nuerk, & Fischer, 2008). Such an association is shown, for instance, by the SNARC (spatial–numerical association of response codes) effect (Dehaene, Bossini, & Giraux, 1993); responses to relatively small numbers are performed faster on the left side (e.g., with the left hand or button), whereas responses to large numbers are performed faster on the right side, even if the task does not require direct magnitude processing (e.g., in parity judgment). It has been argued that this kind of effect reflects mapping numbers onto the horizontal dimension from left to right (mental number line model).

The most prominent explanation of the origins of the left-to-right number representation accentuates the special role of enculturation (for a recent review, see Goebel, Shaki, & Fischer, 2011). Many

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authors assume that spatial–numerical associations are predominantly shaped by reading direction specific to a given culture (Dehaene et al., 1993; Shaki, Fischer, & Petrusic, 2009; Zebian, 2005) and also by the direction of numerical orders (Lindemann, Abolafia, Pratt, & Bekkering, 2008) or measuring tools (Bächtold, Baumüller, & Brugger, 1998). In effect, it is widely believed that this kind of number–space mapping does not emerge before the beginning of primary school, when most of these directional tools are introduced for the first time (van Galen & Reitsma, 2008).

We claim, nevertheless, that these data do not necessarily imply that the left-to-right spatial organization of number magnitudes evolves entirely on the basis of the above-studied experiences, although their impact is indisputable. Recently, left-to-right bias was found in the sequential search for a given numerically determined (e.g., fourth, sixth) position in an ordered row of objects in preliterate preschoolers (Opfer, Thompson, & Furlong, 2010) and even in birds (Rugani, Kelly, Szelest, Regolin, & Vallortigara, 2010). Thus, it seems that preliterate experiences and biological constitution can also be considered as explanations for the directional preferences in numerical representation. It should then be investigated whether cultural experiences such as reading, writing, and mathematical tools are indeed crucial factors for creating spatial–numerical associations.

The majority of research about spatial–numerical associations has used digit or number word stimuli, which are acquired together with other cultural tools that could determine the directional biases. However, it is often claimed that symbolic number representations may originate from a nonsymbolic approximate system for numerosity processing that develops spontaneously and prior to education in infants, nonliterate tribal cultures, and several species of animals (Feigenson, Dehaene, & Spelke, 2004). Importantly, nonverbal numerical estimation may interact with the processing of spatial length in infants and preliterate children (de Hevia & Spelke, 2009, 2010; Lourenco & Longo, 2010), suggesting initial predisposition of the human mind to connect numbers with space in general. However, it is unclear whether such a connection is also formed as a left-to-right spatially organized representation similar to that in older children familiar with reading and writing. So far, nonverbal spatial–numerical effects have been found in adults who were estimating outcomes in a nonsymbolic addition/subtraction task (Knops, Viarouge, & Dehaene, 2009) or approximating non-numerical magnitudes such as duration (Vallesi, Binns, & Shallice, 2008). These studies confirmed the validity of using nonsymbolic stimuli in spatial–numerical tasks, but no research with younger participants has been yet reported.

In the current study, we have designed a task based on nonsymbolic numerosity processing and recruited young preschoolers who had not yet been formally schooled and had not yet acquired counting principles (CP knowledge), which is regarded as a crucial step in the development of a symbolic number system (Le Corre & Carey, 2007). It allowed us to study the spatial–numerical associations not only before literacy acquisition but also before the influence of mathematical language.

A typical SNARC task with bimanual reactions to a central target (Dehaene et al., 1993) requires arbitrary mapping between the response and the response key, which is too demanding for young preschoolers. Some other SNARC research designs seem to be more suitable for this age group, including bilaterally presented stimuli (Zebian, 2005) and single-hand responses (Fischer, 2003). We adapted these methods in our task. Children were asked to point with the right hand to either the smaller or larger one of two sets of rectangles, displayed consecutively on both sides of the touch-screen computer display. The interaction consisting of shorter reaction times (RTs) for the "less" targets, displayed on the left side, and for the "more" targets, displayed on the right side, was regarded as an index of the spatial–numerical congruity (SNC) effect, which might be considered as analogous to the classical SNARC effect. To ascertain whether the performance of our participants was based on a nonverbal quantity estimation, we controlled the effect of ratio between the compared sets, which is the main signature of the analogue number system (Feigenson et al., 2004).

Method

Participants

The participants were 96 children (mean age = 4 years 0 months (4;0), range = 2;8–4;11) from 10 preschools in Warsaw, Poland. An additional 35 children were tested but needed to be excluded