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The underlying number–space mapping among kindergarteners and its relation with early numerical abilities

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People map numbers onto space. The well-replicated SNARC (spatial–numerical association of response codes) effect indicates that people have a left-sided bias when responding to small numbers and a right-sided bias when responding to large numbers. This study examined whether such spatial codes were tagged to the ordinal or magnitude information of numbers among kindergarteners and whether it was related to early numerical abilities. Based on the traditional magnitude judgment task, we developed two variant tasks—namely the month judgment task and dot judgment task—to elicit ordinal and magnitude processing of numbers, respectively. Results showed that kindergarteners oriented small numbers toward the left side and large numbers toward the right side when processing the ordinal information of numbers in the month judgment task but not when processing the magnitude information in the number judgment task and dot judgment task, suggesting that the left-to-right spatial bias was probably tagged to the ordinal but not magnitude property of numbers. Moreover, the strength of the SNARC effect was not related to early numerical abilities. These findings have important implications for the early spatial representation of numbers and its role in numerical performance among kindergarteners.

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Introduction

The SNARC effect

People often represent numbers with space—small numbers being mapped onto the left-hand side and large numbers being mapped onto the right-hand side. This is known as the SNARC (spatial–numerical association of response codes) effect (Dehaene, Bossini, & Giraux, 1993; Dehaene, Dupoux, & Mehler, 1990), which is often demonstrated in the magnitude judgment task and parity judgment task. In both tasks, participants see a digit. In the magnitude judgment task, participants need to decide whether the digit is larger or smaller than 5 (Dehaene et al., 1990; van Galen & Reitsma, 2008); in the parity judgment task, they need to decide whether the digit is odd or even (Dehaene et al., 1993). In both tasks, participants must indicate their decision by pressing a right or left key on the keyboard. Results show that smaller numbers are responded to faster by pressing a left key, whereas larger numbers are responded to faster by pressing a right key, indicating a left-to-right preference in representing increasingly large numbers.

The SNARC effect is often interpreted as mentally representing numbers in the form of a horizontal number line, along which numerical magnitude is positioned in ascending order depending on our reading habits (Dehaene et al., 1993). Recently, it has been suggested that working memory may play a role in the SNARC effect (van Dijck & Fias, 2011). In particular, the ordinal position of numbers in working memory appears to determine the number–space association, and such association may disappear when working memory is overloaded (van Dijck, Gevers, & Fias, 2009). Such a proposal has been supported by findings where people tag spatial codes to numbers depending on the relative positions of the numbers in the sequence rehearsed in working memory instead of the numerical magnitude (van Dijck & Fias, 2011).

Developmentally speaking, the number–space relation appears to emerge during early childhood (de Hevia, Girelli, & Cassia, 2012), and the strength of such relation does not show much change across age (Yang et al., 2014). In particular, preschoolers and elementary school children seem to have already developed spatial representation for numbers. When judging whether a number is odd or even in a parity judgment task, 9-year-olds (Berch, Foley, Hill, & Ryan, 1999), 7.5-year-olds (White, Szücs, & Soltész, 2011), and even 5.8-year-olds (Yang et al., 2014) respond to small numbers faster by pressing a left key and to large numbers faster by pressing a right key. Such number–space association is also evident among 7- to 9-year-olds (van Galen & Reitsma, 2008) and appears to emerge among 5.8-year-olds (Hoffmann, Hornung, Martin, & Schiltz, 2013) when they are asked to press a left or right key if a number is larger or smaller than 5 in a magnitude judgment task. Hence, it appears that preschoolers who are approaching 6 years of age may already be able to associate numbers with space. Because preschool is a critical stage for number symbol mastery, which prepares children for formal numerical learning in elementary school, we focused our investigation into the number–space association particularly on preschoolers and explored how such association might be related to early numerical competencies.

The underlying number–space mapping

The parity judgment task and magnitude judgment task are typical tasks used for examining the SNARC effect. However, they actually elicit different levels of numerical processing (Hoffmann et al., 2013). First, participants are asked to compare the numerical magnitudes in the magnitude judgment task but not in the parity judgment task. Hence, access to the numerical magnitudes in the magnitude judgment task is actually explicit and intentional, whereas access to the irrelevant numerical magnitudes—if any—in the parity judgment task is regarded as implicit and automatic. Tasks that elicit intentional (explicit) and automatic (implicit) processing actually tap into different levels of numerical magnitude processing (Bugden & Ansari, 2011). Second, the magnitude judgment task requires activation of *exact* numerical magnitudes, whereas the parity judgment task does not require any activation of numerical magnitudes; thus, even if numerical magnitudes are indeed activated, they may be approximations only. *How* (implicit vs. explicit) and *what* (approximate vs. exact) numerical