From Text Direction to the Number Line: How Cultural Reading Systems and Education Shape Numerical-Spatial Mapping

Thi Hong Dung Phan
The University of Queensland
thihongdung.phan@student.uq.edu.au

Rhonda Faragher
The University of Queensland
r.faragher.uq.edu.au

Robyn Gillies
The University of Queensland
r.gillies@uq.edu.au

Numerical magnitude is often represented along a spatial continuum known as the mental number line, with magnitudes increasing from left to right. Cross-cultural studies indicate that reading direction influences the orientation of these spatial numerical mappings, while developmental research suggests that formal schooling plays a crucial role in promoting more precise number line representations. This paper reviews how reading direction and education shape spatial-numerical associations, discusses implications for future research and highlights the need to understand the connections between the mental number lines, number sense and learning mathematics.

Introduction

The concept of the mental number line (MNL) can be traced back to Francis Galton's work in 1880, which first documented the spatial nature of numerical thinking by showing that individuals often visualise numbers arranged in space (Dehaene, 2011). Building on this early insight, Dehaene (2011) defined the MNL as the internal representation of numerical quantities, which is "metaphorically thought of as being oriented in space" (p. 81). It is commonly conceived as a left-to-right spatial continuum on which smaller numbers occupy the left side and with numbers increasing towards the right.

The phenomenon of left/small to right/large representation of numbers is called the Spatial-Numerical-Associations of Response Codes (SNARC) effect (Dehaene, 2011). However, the spatial-numerical mapping is not universal, and may be influenced by reading direction and education. Additionally, little is known about the implications of a MNL for number sense, how the development of the MNL could be enhanced by teaching, and then the implications for learners with an impaired MNL. Hence, the present paper aims to review how the MNL is studied and how cultural reading systems and education shape how we map numbers onto space. Finally, implications for future research and for mathematics teaching are discussed.

Studies about the mental number line

In the literature, the term MNL is sometimes used interchangeably with "number line", yet the latter may also refer to a concrete, physical instructional representation used in mathematics teaching. Schneider and colleagues (2009) explicitly distinguished the internal number line, referring to mental magnitude representation, from the external number line, referring to its physical visual display. Despite this distinction, both forms share key structural properties, comparatively representing numerical magnitude, typically as a one-dimensional scale (Schneider et al., 2009).

Origin of MNL and its connection with number sense and mathematics learning

The origins of the MNL remain a subject of debate. Some evidence has shown that the MNL is biologically rooted, as studies with babies and animals indicate early sensitivity to numerical magnitude. In contrast, Nunez (2011) assumes that there is no innate MNL, with the MNL acquired only though cultural practices and educational exposure. Supporting this view, he

(2026). In N. Berger, M. Thompson, J. Ley & C. Wilsmore (Eds.), *Beyond boundaries: Strengthening futures in mathematics education. Proceedings of the 48th annual conference of the Mathematics Education Research Group of Australasia, Sydney* (pp. 313–320). MERGA.

described research involving the Munduruku group, a remote and isolated Indigenous community with limited exposure to formal education or measuring tools. These people reported difficulty in representing even small numbers such as one, two and three on a line segment. Nunez therefore concluded that a linear number line described by Siegler and Opfer (2003) was a product of culture and formal education.

Closely related to the mental number line is the concept of number sense. Dehaene (2011) argues that humans are born with an intuitive ability to perceive and compare numerical quantities. Infants can precisely recognise small quantities (typically up to three or four) and estimate larger quantities approximately. Evidence of number sense is also observed in adults' subitizing ability, which allows individuals to recognise small quantities without counting (Dehaene, 2011). Humans possess an innate approximate number system. How this is represented is not known, though it may be represented on a mental number line.

There is also a connection between the MNL, number sense and mathematics learning. Griffin et al. (1994) designed the RightStart training program. Before the training, almost all kindergarten participants from low-income families in Canada and the US failed the 6-year-old level of number knowledge tests, and even many of them failed at items for the 4-year-old level. They could not tell which number is larger: 6 or 8, or which of 2 or 6 is closer to 5. These difficulties indicate the absence of general number knowledge inherent in a mental comparative representation, such as on a number line. The RightStart program was designed to focus on the intuitive representation of quantities on a mental number line. After the forty 20-minute sessions of training with the RightStart program, taking around 4 to 5 months, the great majority of the children passed the tests, and they even outperformed the control group who received a traditional curriculum. Their gains were also consolidated in the next school year. The success provides evidence to support the importance of the MNL and intuition of numbers in mathematics learning.

Where the brain stores the mental number line

In addition to the origin of MNL and its link with number sense and mathematics learning, studies of the MNL have investigated if there is a specific region of the brain for MNL representation. Many of these have used clinical studies, such as imaging and patient observation. Other studies have focused on understanding characteristics of MNL representations.

Evidence supports the parietal cortex playing a crucial role in mental representations of numbers (Dehaene, 2011). Abdullaev and Melnichuk (1996), using implanted cortical electrodes, recorded activity of neurones of the parietal cortex when doing arithmetic and language tasks. They found neurones in both left and right parietal cortex became active only when numerals were shown and most neurones fired more strongly during counting and calculation than during reading the same numbers as words. This finding indicates the parietal cortex is involved in number processing operations. A later meta-analysis review based on neuroimaging and neuropsychological evidence by Dehaene and colleagues (2003) found that the horizontal segment of the intraparietal sulcus appears to be the most likely site for representing numerical magnitudes.

Further evidence arising from clinical observation by a German neurologist, Gerstmann (1940 discussed in Dehaene, 2011) described a patient who suffered a lesion of the left inferior parietal region, who showed a deficit in quantitative representations of numbers. This suggests that this area of the brain plays a key role in processing numerical magnitudes and the damage to the inferior parietal area may be responsible for his loss of number sense (Dehaene, 2011).

Finally, the way the brain represent numbers appears to follow principles that are very similar to the structure of the hand's layout (Dehaene, 2011). For example, the above patient confused his index finger with his middle finger when prompted. Dehaene (2011) thus assumed a possible connection between numbers and finger use indicating that body maps, spatial maps and the mental number line may all stem from a single structural principle that shapes connectivity in the inferior parietal cortex. It is unclear at this stage where the brain stores a MNL representation, though it is plausible that it is in the parts of the brain that are known to be used for other representations of quantity.

Studies about characteristics of MNL representations

The MNL is commonly investigated using three different approaches: number line estimation tasks, the distance effect and the SNARC effect. These are discussed in turn.

Number line estimation tasks

The number line estimation task is popular for investigating the mental number line as it explicitly requires mapping numbers onto space (Siegler & Opfer, 2003). The tasks include number-to-position tasks and position-to-number tasks. In number-to-position tasks, participants are asked to place a given number on a number line; while in position-to-number tasks, participants are required to identify the number corresponding to a given position.

The number line estimation task has been used to test three different ways participants might use to represent numbers: the logarithmic-ruler representation, the linear-ruler representation or variable representations, depending on the age of the participant and the numerical context in which the task was given. "Logarithmic representation exaggerates the distance between magnitudes of numbers at the low end and minimizes the distance at the middle and high ends" (Siegler & Booth, 2004, p. 429). For example, the represented distance between 1 and 75 would be bigger than that between 75 and 1000. In linear-ruler representations, numbers are spaced evenly with linearly increasing magnitudes (Siegler & Booth, 2004).

Distance effect

In tasks that require participants to judge which of two numbers is larger, a distance effect (first documented by Moyer and Landauer, 1967) has been noted. When the distance between two numbers is large, for example 2 and 9, participants answer quickly and accurately; however, when two numbers are closer, for example 5 and 6, response times are slower. Additionally, for equal distances between pairs of numbers such as 1 and 2, and 8 and 9, with both having the same distance of one unit, the response time for the pair 8 and 9 is slower than the pair 1 and 2. The pattern also occurs in comparing two-digit numerals, that the response time increases continuously when the numbers are increasingly close (Dehaene et al., 1990). For example, 71 and 65 takes more time to compare than 79 and 65. The authors concluded the strong distance effect supports analogue magnitude processing, which means two-digit numbers were encoded as whole-magnitude numbers, rather than comparing the digits (tens and units) separately, and transformed into mental number line representations.

SNARC effect

SNARC effect, another indicator of a MNL, refers to the mental representation of numbers, typically in a left-to-right orientation (Dehaene, 2011). This effect was observed in a study where participants were instructed to classify two numbers as smaller or larger. They held two response keys, one on the left and another one on the right. The experiment found that the subjects responded faster with fewer errors when they pressed the left key for small numbers and the right key for larger numbers (Dehaene, 2011). Similarly, in other experiments, participants were required to determine if one-digit numbers were odd or even, on a "parity judgment" task (Dehaene et al., 1993). Half of the participants were asked to press the right response key for an odd number and the left response key for an even number, then they went through with the reverse responses to keys. The other half of participants did the same but with reverse order. Regardless of instruction, they also found the same effect, with the left-hand responses faster than right hand responses for small odd or even numbers, while the right-hand responses were faster for large odd or even numbers.

Cultural Reading Direction and Spatial–Numerical Mapping

The generation of the MNL has two possible origins: an innate, representation of biological origin or one that is at least influenced by teaching approaches and educational experience.

Cross-Cultural Evidence

One of the strongest challenges to the idea of a universal, biologically fixed MNL comes from cross-cultural research examining reading direction. Studies comparing left-to-right and right-to-left reading populations consistently show differences in SNARC direction (Dehaene et al., 1993; Shaki & Fischer, 2008, 2012; Shaki et al., 2009; Wood et al., 2008; Zebian, 2005). For example, in populations whose writing systems proceed from left to right such as English, French, and Canadian readers, the classic SNARC pattern is consistently observed, with numerical magnitude increasing from left to right (Dehaene et al., 1993; Fischer, 2008; Shaki et al., 2009; Zebian, 2005). These findings initially appeared to support the notion of a left-to-right spatial representation of numerical magnitude for learners in general.

However, evidence from right-to-left reading cultures complicates this interpretation. Studies involving Palestinian, Iranian, Hebrew, and Arabic readers have reported either reversed SNARC effects or attenuated patterns consistent with their habitual scanning direction (Dehaene et al., 1993; Shaki et al., 2009; Zebian, 2005). In these populations, smaller numbers are often associated with the right side of space and larger numbers with the left. Such findings indicate that reading direction systematically influences the orientation of spatial–numerical mapping rather than reflecting a universally fixed spatial structure.

Moreover, reading orientation is not limited to horizontal formats. In cultures where texts are traditionally arranged vertically such as Chinese, Taiwanese, and Japanese contexts, spatial-numerical associations can also follow vertical patterns. For example, Japanese participants have been shown to associate smaller numbers with lower spatial positions and larger numbers with upper positions (Ito & Hatta, 2004). Intriguingly, this is opposite to their reading direction. In contrast, Hung et al. (2008) found that Taiwanese participants demonstrated spatial–numerical mappings consistent with the vertical orientation of traditional Chinese texts, specifically, small numbers on the top and large numbers on the bottom.

To show consistent spatial mapping, reading systems need to be the same direction for both words and numbers. For example, Israeli students read words from right to left while reading numbers from left to right. In a study by Shaki et al. (2009), participants did not exhibit a clear SNARC effect, possibly due to conflicting spatial experiences. This finding suggests that congruency between reading habits for words and numbers may be necessary for stable spatial–numerical mapping.

Together, these findings suggest that reading orientation, whether left-to-right, right-to-left, or top-to-bottom plays a significant role in shaping how numerical magnitude is spatially organized.

Bilingual and Bidirectional Readers

Research on bilingual and bidirectional readers provides important insight into how reading experience shapes spatial–numerical mapping. Individuals who are fluent in languages with opposing reading directions often display context-dependent SNARC effects (Shaki & Fischer, 2008). In other words, the orientation of spatial–numerical associations can shift depending on the linguistic context activated during the task. For example, the authors asked Russian–Hebrew bilingual university students, whose mother-tongue was Russian and spoke Hebrew for at least seven years, to read a short paragraph in either Russian (left-to-right) or Hebrew (right-to-left) before completing a parity judgment task. After reading Russian, participants exhibited the typical left-to-right SNARC effect; but after reading Hebrew, the effect was substantially weaker. A similar study with Russian-Hebrew university bilinguals by Fischer and colleagues (2009) found that when the participants classified number words (presented in either Russian or Hebrew) and Arabic digits, the SNARC effect emerged in the Russian context but disappeared in the Hebrew context. Notably, even brief and recent exposure to a single word in a particular script was sufficient to influence spatial–numerical mapping. These findings show that spatial–numerical associations remain flexible and can shift according to the active reading system.

At the same time, language proficiency appears to play a crucial role. When second-language competence is limited, spatial–numerical mapping tends to align with the dominant language. For instance, Zebian (2005) reported that both Arabic–English bilingual adults and children showed a reversed SNARC effect when their English proficiency was low. Similarly, Iranian participants who had recently migrated to France demonstrated reversed SNARC patterns consistent with right-to-left reading habits, whereas Iranian individuals with greater familiarity with left-to-right systems showed weaker reversed effects (Dehaene et al., 1993). Thus, the strength and direction of spatial–numerical mapping are influenced not only by exposure to multiple reading systems but also by the level of language proficiency and contextual activation. The evidence leads to a further question: in individuals who have not yet acquired literacy or who have had limited formal education, does a directional MNL emerge at all?

Illiterate and emerging literacy populations

Research on illiterate populations offers further important insight into the role of literacy in shaping the MNL. Zebian (2005) examined an illiterate Lebanese group who could recognise and read numbers but were unable to read words. Although these individuals were immersed in a right-to-left reading culture, they did not exhibit a reversed SNARC effect; rather, they showed no reliable spatial–numerical association. This finding suggests active engagement with written language may be necessary for spatial–numerical mapping. Given that young children, like illiterate adults, can often count objects and recite numbers before acquiring reading skills, do preschool children also show absent or unstable spatial–numerical associations?

Research (Göbel et al., 2018; Patro et al., 2016) suggests that directional tendencies can emerge before formal literacy instruction begins. For example, Opfer and Thompson (2006) found that 98% of children aged 2.5 to 5.5 years counted objects from left to right. They also found in addition and subtraction tasks, children in the MNL group (mean age = 11.9 years) more consistently added from left to right and subtracted from right to left compared to children in the no MNL group (mean age = 6.36 years). Moreover, children who displayed stable directional patterns performed more accurately when estimating larger quantities beyond the subitising range, even after controlling for age. In Ashkenazi and Mark-Zigdon's (2021) study, Hebrew-speaking preschoolers aged 3.5 to 5 years showed more accurate number-line estimations when the line was oriented from right to left rather than left to right. These findings support the hypothesis that spatial–numerical associations begin to develop early and may be based on involvement in active engagement or passive observation of spatial oriented events, such as reading books, drawing a line, or organising toys on a shelf (Patro et al., 2016).

Among spatial oriented events, shared reading books seems to directly shape young children's counting direction. Even after a short, shared reading session of only two to three minutes, children's preferred counting direction shifted toward the observed orientation (Göbel et al., 2018). Importantly, this effect occurred even when explicit counting activities were not included. Exposure to directional motion in videos did not change their counting preferences.

This shifting is only temporary after the intermediate exposure as their counting direction returned to culturally dominant patterns in a follow-up test, four weeks later.

Studies on finger counting and the SNARC effect in children and adults show different results in participants who read from left to right. In one study (Fischer, 2008), for subjects who prefer counting fingers starting from their left hands, a typical SNARC effect was found and no reliable SNARC effect in the right-starter group. However, other studies have provided contradictory results (see for example, Prete & Tommasi, 2020; Sato & Lalain, 2008). Such investigations remain limited in cultures demonstrating clear reversed SNARC effects (Pitt & Casasanto, 2014). Thus, the precise contribution finger-counting habits have to the formation of the MNL remains unclear (Pitt & Casasanto, 2014).

Overall, findings from preschool children who have not received formal schooling such as reading and mathematics instruction indicate that early spatial–numerical mapping arises from multiple interactions. However, research shows that a proportion of preschoolers (Ashkenazi & Mark-Zigdon, 2021; Opfer & Thompson, 2006) and illiterate adults (Zebian, 2005) display no, weak or inconsistent spatial–numerical associations. These patterns suggest that while directional tendencies may emerge early, formal education plays a crucial role in consolidating and refining them into a stable mental number line.

Education and spatial-numerical mapping

Formal schooling plays a crucial role in shaping how numerical magnitude is spatially organized. In left-to-right reading cultures, educational materials consistently present numbers as increasing from left to right. Tools such as number lines, rulers, graphs, number charts and written arithmetic layouts reinforce this directional structure. Among these, the number line is one of the most explicit instructional devices for representing magnitude. In primary mathematics classrooms, numbers are arranged sequentially along a horizontal line, allowing teachers to visually illustrate concepts of magnitude, numerical distance, and arithmetic operations such as addition and subtraction through spatial movement (Göbel et al., 2011). The illustration of external number lines supports the development of the MNL by providing a spatial model that children can map onto their internal representations (Schneider et al., 2009).

Research demonstrates that instructional use of number lines strengthens children's number sense, numerical understanding and arithmetic performance (Griffin et al., 1994; Ramani & Siegler, 2008; Siegler & Ramani, 2008). Targeted interventions including linear board games (Ramani & Siegler, 2008; Siegler & Ramani, 2008) and structured number lines have been shown to improve numeracy estimation accuracy (Diezmann et al., 2010), which relates strongly to mathematics achievement (Siegler & Booth, 2004). Studies have found numeracy estimation patterns shifted developmentally from predominantly logarithmic representations to a mixture of logarithmic and linear patterns, and eventually to largely linear representations across kindergarten, first-grade and second-grade children (approximately six to eight years old) (Siegler & Booth, 2004) which is a similar estimation pattern to that found by Siegler and Opfer (2003) but with older groups (grade 2, grade 4, grade 6 and adults). Specifically, second graders (mean age: 7.9 years) followed a logarithmic pattern while sixth graders (mean age: 11.8 years) and adults followed a linear pattern. The results indicate numeracy estimation accuracy improvement with age and schooling (Siegler & Opfer, 2003), which is consistent with the strength of the SNARC effect in a meta-analysis by Wood and colleagues (2008) who found that the strength of SNARC effect increases with age. As children gain mathematical experience, their estimation as well as spatial representations of number become more precise, systematic, and aligned with culturally standardised formats. This enhances the precision of the mental number line.

Implications

While there has been a growing body of research improving understanding of how reading systems shape numerical-spatial mapping in adults and typical developing children, little is known how students who might need extra support, such as those with mathematics learning disability, and bilingual children with different reading systems, can be assisted to develop a stable linear MNL. It is unknown whether students with mathematical learning disabilities shape their numerical mapping similarly or differently to typically developing children in a monolinguistic culture or whether their orientation of the MNL is consistent with their reading systems. Future research is needed to deepen the understanding of the development of the MNL for these students. There follows important implications for mathematics teaching. For example, the impact of explicit teaching on the use of external number lines may make it easier for children to represent numbers on a structure that is similar to their internal number line, thus supporting children to develop their MNL (Schneider et al., 2009). In addition, external number lines represent abstract mathematics ideas that help students better understand and operate with different types of numbers (Teppo & Heuvel-Panhuizen, 2014). It is therefore essential to undertake further research to investigate the impact of external representations on MNL development and the subsequent impact on mathematics education for students with learning disabilities and other learning support needs.

Conclusion

In this paper, we have canvassed research literature that has explored how humans store representations of quantity on a mental number line. Much is still to be understood in this field, not least where in the brain this is recorded, and how the representation is developed. It would appear that cultural context and education, along with age-related growth and development are important. Reading directions and education play an important role in shaping how learners map numerical information onto space. Teaching is likely to guide students in how to map the spatial-numerical association aligned with their reading system whether left-to-right, right-to-left or top-to-bottom reading direction. This helps construct the MNL, which supports magnitude understanding, arithmetic and mathematics learning more broadly. It is therefore critical to understand the impact on learners who may require extra support from teachers.

References

Abdullaev, Y. G., & Melnichuk, K. V. (1996). Counting and arithmetic functions of neurons in the human parietal cortex. *NeuroImage (Orlando, Fla.)*, *3*(3), S216–S216.

Ashkenazi, S., & Mark-Zigdon, N. (2021). Directionality of number space associations in Hebrew-speaking children: Evidence from number line estimation. In M. Herzog, E. Gürsoy, & A. Fritz (Eds.), *Diversity Dimensions in Mathematics and Language Learning* (Vol. 24, pp. 163–182). Walter de Gruyter GmbH.

Dehaene, S. (2011). The number sense: How the mind creates mathematics. OUP USA.

Dehaene, S., Bossini, S., & Giraux, P. (1993). The mental representation of parity and number magnitude. *Journal of Experimental Psychology*. *General, 122*(3), 371-396.

Dehaene, S., Dupoux, E., & Mehler, J. (1990). Is numerical comparison digital? Analogical and symbolic effects in two-digit number comparison. *Journal of Experimental Psychology. Human Perception and Performance*, *16*(3), 626–641. https://doi.org/10.1037/0096-1523.16.3.626

Dehaene, S., Piazza, M., Pinel, P., & Cohen, L. (2003). Three parietal circuits for number processing. *Cognitive Neuropsychology*, *20*(3–6), 487–506.

Diezmann, C. M., Lowrie, T., & Sugars, L. A. (2010). Primary students' success on the structured number line. *Australian Primary Mathematics Classroom, 15*(4), 24-28.

Fischer, M. H. (2008). Finger counting habits modulate spatial-numerical associations. *Cortex*, *44*(4), 386-392. https://doi.org/10.1016/j.cortex.2007.08.004

Fischer, M. H., Shaki, S., & Cruise, A. (2009). It takes just one word to quash a SNARC. *Experimental Psychology*, *56*(5), 361-366. https://doi.org/10.1027/1618-3169.56.5.361

Göbel, S. M., McCrink, K., Fischer, M. H., & Shaki, S. (2018). Observation of directional storybook reading influences young children's counting direction. *Journal of Experimental Child Psychology*, *166*, 49-66.

Göbel, S. M., Shaki, S., & Fischer, M. H. (2011). The cultural number line: A review of cultural and linguistic influences on the development of number processing. *Journal of Cross-Cultural Psychology*, *42*(4), 543-565. https://doi.org/10.1177/0022022111406251

Griffin, S. A., Case, R., & Siegler, R. S. (1994). RightStart: Providing the central conceptual prerequisites for first formal learning of arithmetic to students at risk for school failure. In K. McGilly (Ed.) (1996), *Classroom lessons: Integrating cognitive theory and classroom practice* (pp. 25–49). The MIT Press. https://doi.org/10.7551/mitpress/1861.003.0007

Hung, Y.-h., Hung, D. L., Tzeng, O. J. L., & Wu, D. H. (2008). Flexible spatial mapping of different notations of numbers in Chinese readers. *Cognition*, *106*(3), 1441-1450.

Ito, Y., & Hatta, T. (2004). Spatial structure of quantitative representation of numbers: Evidence from the SNARC effect. *Memory & Cognition*, *32*(4), 662-673. https://doi.org/10.3758/BF03195857

Moyer, R. S., & Landauer, T. K. (1967). Time required for judgements of numerical inequality. *Nature*, *215*(5109), 1519–1520. https://doi.org/10.1038/2151519a0

Nunez, R. E. (2011). No innate number line in the human brain. *Journal of Cross-Cultural Psychology*, *42*(4), 651–668. https://doi.org/10.1177/0022022111406097

Opfer, J. E., & Thompson, C. A. (2006). Even early representations of numerical magnitude are spatially organized: Evidence for a directional magnitude bias in pre-reading preschoolers. *Proceedings of the Annual Meeting of the Cognitive Science Society, 28*(28). Retrieved from https://escholarship.org/uc/item/4477g2wg

Patro, K., Nuerk, H.-C., & Cress, U. (2016). Mental number line in the preliterate brain: The role of early directional experiences. *Child Development Perspectives, 10*(3), 172–177.

Pitt, B., & Casasanto, D. (2014). Experiential origins of the mental number line. *Proceedings of the Annual Meeting of the Cognitive Science Society, 36*(36).

Prete, G., & Tommasi, L. (2020). Exploring the interactions among SNARC effect, finger counting direction and embodied cognition. *PeerJ (San Francisco, CA)*, *8*(3), Article e9155.

Ramani, G. B., & Siegler, R. S. (2008). Promoting broad and stable improvements in low-income children's numerical knowledge through playing number board games. *Child Development*, *79*(2), 375-394.

Sato, M., & Lalain, M. (2008). On the relationship between handedness and hand-digit mapping in finger counting. *Cortex*, *44*(4), 393-399. https://doi.org/10.1016/j.cortex.2007.08.005

Schneider, M., Grabner, R. H., & Paetsch, J. (2009). Mental number line, number line estimation, and mathematical achievement: Their interrelations in grades 5 and 6. *Journal of Educational Psychology*, *101*(2), 359-372. https://doi.org/10.1037/a0013840

Shaki, S., & Fischer, M. H. (2008). Reading space into numbers – a cross-linguistic comparison of the SNARC effect. *Cognition*, *108*(2), 590-599. https://doi.org/10.1016/j.cognition.2008.04.001

Shaki, S., & Fischer, M. H. (2012). Multiple spatial mappings in numerical cognition. *Journal of Experimental Psychology: Human Perception and Performance*, *38*(3), 804-809.

Shaki, S., Fischer, M. H., & Petrusic, W. M. (2009). Reading habits for both words and numbers contribute to the SNARC effect. *Psychonomic Bulletin & Review*, *16*(2), 328-331.

Siegler, R. S., & Booth, J. L. (2004). Development of numerical estimation in young children. *Child Development*, *75*(2), 428-444. https://doi.org/10.1111/j.1467-8624.2004.00684.x

Siegler, R. S., & Opfer, J. E. (2003). The development of numerical estimation: Evidence for multiple representations of numerical quantity. *Psychological Science*, *14*(3), 237-243.

Siegler, R. S., & Ramani, G. B. (2008). Playing linear numerical board games promotes low-income children's numerical development. *Developmental Science*, *11*(5), 655-661.

Teppo, A., & Heuvel-Panhuizen, M. (2014). Visual representations as objects of analysis: the number line as an example. *ZDM*, *46*(1), 45–58. https://doi.org/10.1007/s11858-013-0518-2

Wood, G., Willmes, K., Nuerk, H.-C., & Fischer, M. H. (2008). On the cognitive link between space and number: a meta-analysis of the SNARC effect. *Psychology Science*, *50*(4), 489.

Zebian, S. (2005). Linkages between number concepts, spatial thinking, and directionality of writing: The SNARC effect and the reverse SNARC effect in English and Arabic monoliterates, biliterates, and illiterate Arabic speakers. *Journal of Cognition and Culture*, *5*(1-2), 165-190.