

# The role of spatial skills in early math learning and how to foster space-number interactions

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*Understanding the link between number and space is shedding new light on the potential importance of many toys and games for developing children's mathematical abilities.*

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## Executive summary

- Research from psychology and neuroscience indicates that our brain learns to represent and manipulate numerical quantities in a way that is grounded in spatial processing. This may offer multiple ways to foster math skills through the use of activities involving spatial thinking in children.
- In practical terms, spatial thinking may benefit from certain types of play in children, such as the use of construction toys, tangrams, or activities that involve mental rotation, and from parents often using language that describes spatial relations (e.g., above, below, left, right) and spatial information in general (e.g., geometrical shapes).
- A growing body of research indicates that playing number board games and giving children tasks in which they estimate the spatial position of numbers on a line may also be useful ways to foster numerical thinking.

## Introduction

There are several examples of evident links between math and space<sup>[1]</sup>. For example, understanding positional notation in the Hindu–Arabic numeral system (i.e., the fact that the position of a digit in a number determines its value) requires processing spatial information. Adding, subtracting, multiplying, and dividing multi-digit numbers on a piece of paper also involves positioning numbers in space. Finally, spatial skills have an obvious role in geometry, where models have to be maintained and manipulated in space. Importantly, however, cognitive psychology and neuroscience research indicate that the contribution of spatial processing to numerical cognition is not restricted to these examples. In fact, spatial processing may be at the very heart of early math learning in children because spatial coding may underlie the representation of numerical quantities. This may explain why children with poor visuospatial skills often struggle with math and whether low visuospatial ability is a hallmark of children with a math learning disability<sup>[1]</sup>.

### The spatial representation of numerical quantities

One of the earliest demonstrations that numbers are spatially encoded in the human brain comes from an experiment conducted in 1993 by Dehaene and colleagues<sup>[2]</sup>. The researchers wanted to study the way adults process even and odd numbers. Therefore, they presented participants with numbers from 0 to 9 on a computer screen and asked participants to decide whether the number was even or odd. In half of the experiment, participants pressed a key located on the left side of the keyboard if the number was odd and a key located on the right side of the keyboard if the number was even. This assignment was reversed in the second half of the experiment, such that the odd key was then located on the right side and the even key on the left side. The researchers made a striking discovery: small numbers (e.g., 1, 2) were processed faster when participants pressed the left key than the right key, and large numbers (e.g., 8, 9) were processed faster when participants pressed the right key than the left key. Therefore, it appears that numbers may be spatially organized in the adult mind, with quantities of increasing size running from left to right.

It is clear that the spatial organization of numbers in the adult mind may be influenced by cultural factors (e.g., left-to-right reading habits). However, recent studies suggest that this organization may (at least in part) be independent from individual experiences and instead have an ancient evolutionary origin. For instance, a recent experiment showed that 8- to 9-month-olds automatically move their attention to the left after perceiving small numerical quantities and to the right after perceiving larger numerical quantities<sup>[3]</sup>. Another study even found that baby chickens associate small and large quantities to the left and right side of space (respectively)<sup>[4]</sup>! Therefore, research indicates that numbers may have a left-to-right organization in the brain, and that this organization may be quite primitive.

### Space and arithmetic

At first glance, it is not obvious to what extent this spatial organization of numerical quantities affects math processing in adults. For instance, one certainly does not have the feeling of manipulating numbers in space when solving  $2 + 3$  or  $7 - 3$ . Yet, studies do suggest that our brain may rely on spatial intuitions when solving arithmetic problems. For example, Knops and colleagues measured the cerebral activity of participants while they solved addition and subtraction problems in a brain scanner<sup>[5]</sup>. They found that the brain regions that were activated during addition problem-solving were very similar to the brain regions that are activated when participants had to move their eyes towards the right side of space. Conversely, the brain regions that were activated during subtraction problem-solving were very similar to the brain regions that were

activated when participants had to move their eyes towards the left side of space (see Figure 1). Therefore, as far as our brain mechanisms are concerned, solving an addition problem may be comparable to moving attention towards the right side of a mental “number line,” whereas solving a subtraction problem may evoke a leftward movement along that line. For example, solving  $5 + 3$  or  $5 - 3$  may be conceptualized as moving 3 units to the right or left of the number 5, respectively. This hypothesis has been confirmed by other studies. For instance, researchers have found that simple addition problems tend to be solved faster by educated adults when the second number in the operation (i.e., 3 in “ $5 + 3$ ”) is presented in the right side of space than when it is presented in the left side<sup>[6]</sup>. The opposite effect is observed for simple subtraction problems (i.e., these are solved faster when the second operand is presented in the left side of space). Therefore, the spatial organization of numerical quantities in the brain may have far-reaching consequences on many aspects of math skills, including the way we solve very basic arithmetic problems.

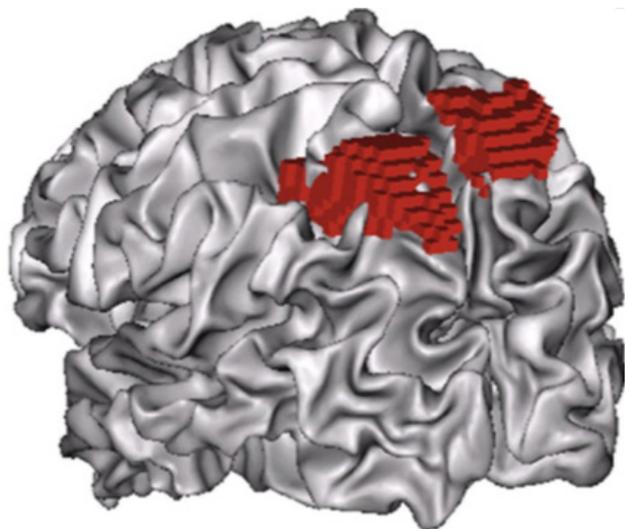
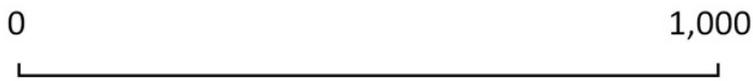


Figure 1. Interactions between number and space in the brain. Brain regions involved in solving arithmetic problems and making eye movements (in red) on a 3D representation of the brain taken using magnetic resonance imaging. (Reproduced from ref. <sup>[5]</sup>).

### The importance of spatial-numerical associations for math learning

Several studies indicate that the quality of spatial-numerical mappings is critical for early math learning in children. For instance, as children become more and more familiar with numerical symbols in elementary school, they increase the precision of their representation of numbers in space. This is typically evaluated with tasks in which children are asked to position a given number on a line drawn on a piece of paper, with 0 or 1 at one end and a larger number (typically varying from 10 to 1,000) at the other hand (see Figure 2). Younger children tend to overestimate the position of relatively small numbers to the right (e.g., they tend to put 8 at about the position of 30). This compresses the positions of large numbers towards the end of the scale. With age and experience, however, these errors usually disappear and children will exhibit a more linear and precise representation throughout the entire scale<sup>[7]</sup>. Interestingly, the extent to which placements of numbers are linear in such tasks is both predicted by children’s spatial abilities and correlated with math skills<sup>[1,7]</sup>. Therefore, children’s spatial skills may influence the quality of their linear representation of numbers, which in turn plays an important role in early math learning.



“If this is where 0 goes and this is where 1,000 goes,  
where does 86 go?”

Figure 2. Example of a visual number line task.

### Using space to foster numerical skills

The link between number-space associations and math skills naturally suggests that it might be interesting to stimulate children's spatial abilities during math learning. For example, a study found an improvement in arithmetic performance of 6- to 8-year-olds after practice of a task involving mental rotation<sup>[18]</sup>. The improvement was particularly noticeable for missing term problems, such as  $2 + \_ = 5$ . Other studies have shown that directly enhancing the spatial mapping of numbers may have several benefits for children. For instance, studies have found that giving corrective feedback to children when they wrongly place a number on a visual line may lead to improvements in future estimations<sup>[7]</sup>. Training on such visual line tasks is also associated with reductions of activity in several brain regions, most likely indicating an increase in the automatization of processes involved in math skills<sup>[9]</sup> (see Figure 3).

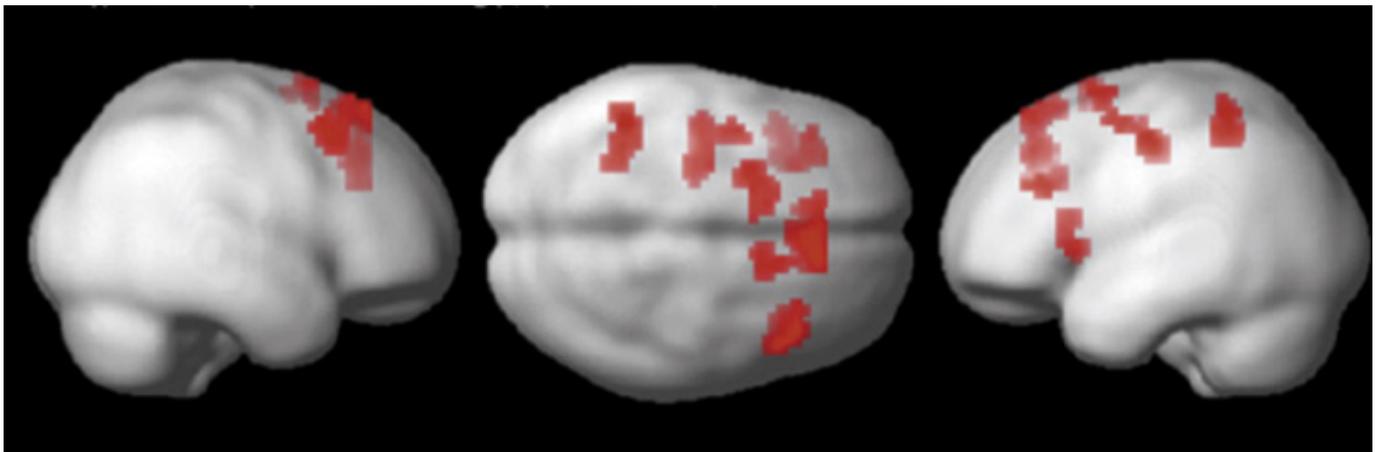


Figure 3. Changes in brain activity (in red) after number line training in 8- to 10-year-olds. Brain regions showing less activity in a numerical task after repeated exposure (with feedback) with a number line task. Brain regions are overlaid on a 3D representation of the brain taken using magnetic resonance imaging. (Reproduced from ref. <sup>[9]</sup>).

But enhancing number-space mappings may not necessarily require specific number line tasks<sup>[7]</sup>. Board games in which children navigate along a sequential arrangement of numbered squares, such as the popular game “Chutes and Ladders,” may also be beneficial. For instance, a team of researchers asked preschoolers to play a board game in which they had to move a token from the left to the right of a sequence of numbered squares (see Figure 4). They found that, compared to playing a board game in which squares were not numbered but simply colored, playing this number board game led to improvements in skills such as counting, numeral identification, quantity comparison, and linearity of the number line<sup>[7]</sup>. This might be because playing board games in which children move a token along a sequence of numbered squares may provide them with several cues that are important when learning about numerical magnitudes. For example, as hypothesized by one of the researchers involved in this discovery, “the greater the number in a square, the greater (a) the number of discrete movements of the token the child needs to make to reach it, (b) the number of number names the child says before reaching it, (c) the distance traveled from the origin to reach it, and (d) the time that passes before reaching it”<sup>[7]</sup>. The fact that number-space mapping can be explicitly trained has also been demonstrated by a recent experiment in which kindergartners were asked to compare numerical quantities while making congruent body movements on a dance mat (e.g., moving their foot to

the left for smaller numbers and to the right for larger numbers)<sup>[7]</sup>. Compared to a training in which no spatial movements were required, researchers found that this program—based on sensori-motor spatial training—led to overall improvements in math skills as well as in linearity of the number line<sup>[10]</sup>.



Figure 4. Example of a board game that can be used to improve children's numerical skills. (Reproduced from ref. [7]).

## Conclusion

In sum, psychology and neuroscience research points to a clear link between spatial abilities and early numerical skills. This suggests that the growth of children's mathematical thinking may benefit from an environment that promotes spatial skills. More practically, research shows that spatial thinking may benefit from certain types of play in children, such as the use of construction toys, tangrams, or activities that involve mental rotation<sup>[11]</sup>. It may also be interesting for parents to often use language that describes spatial relations (e.g., above, below, left, right) and spatial information in general (e.g., geometrical shapes). Finally, a growing body of research indicates that playing number board games and giving children tasks in which they estimate the spatial position of numbers on a line may be useful ways to foster numerical thinking<sup>[7]</sup>. In sum, the fact that numerical representations are grounded in space offers multiple ways to foster math skills through the use of activities involving spatial thinking in children.

## References

1. Crollen, V. and M.P. Noël, How does space interact with numbers? In *Visual-spatial Ability in STEM Education*. 2017, Springer International Publishing. p. 241-263.
2. Dehaene, S., S. Bossini, and P. Giraux, The mental representation of parity and number magnitude. *Journal of Experimental Psychology: General*, 1993. 122: p. 371-396.
3. Bulf, H., M.D. Hevia, and V.M. Cassia, Small on the left, large on the right: numbers orient visual attention onto space in preverbal infants. *Developmental science*, in press.
4. Rugani, R., et al. Number-space mapping in the newborn chick resembles humans' mental number line. *Science*, 2015. 347(6221): p. 534-6.
5. Knops, A., et al. Recruitment of an area involved in eye movements during mental arithmetic. *Science*, 2009. 324(5934): p. 1583-5.
6. Mathieu, R., et al. Running the number line: Rapid shifts of attention in single-digit arithmetic. *Cognition*, 2015. 146: p. 229-239.
7. Siegler, R.S., Magnitude knowledge: the common core of numerical development. *Dev Sci*, 2016. 19(3): p. 341-61.
8. Cheng, Y.L. and K.S. Mix, Spatial training improves children's mathematics ability. *Journal of Cognition and Development*, 2014. 15(1): p. 2-11.
9. Kucian, K., et al. Mental number line training in children with developmental dyscalculia. *Neuroimage*, 2011. 57(3): p. 782-95.

10. Fischer, U., *et al.* Sensori-motor spatial training of number magnitude representation. *Psychon Bull Rev*, 2011. 18(1): p. 177-83.
11. Jirout, J.J. and N.S. Newcombe, Building blocks for developing spatial skills: evidence from a large, representative U.S. sample. *Psychol Sci*, 2015. 26(3): p. 302-10.