How do children's brains learn Arabic numerals?

Learning Arabic numerals is an important first step for the acquisition of symbolic mathematics in children. Using neuroimaging measures coupled with machine learning, scientists were able to demonstrate how such symbols become represented in children's brains during the early years of schooling. These findings are published in the journal PLOS Biology.

Previous research suggests that the human brain is endowed with the innate ability to approximate numerical quantities without relying on language or symbols. This provides the first route through which young children may apprehend non-symbolic quantities in preschool, for example when they compare sets of objects. Contrary to other animals, however, humans have also invented symbols to represent and manipulate these quantities, such as Arabic digits. Learning these symbols represent a fundamental first step towards understanding symbolic mathematics. To date, little was known about how representations of Arabic digits emerge in the brain during the first years of schooling. Notably, it was unclear whether these culturally-transmitted symbolic representations are related to evolutionary old brain mechanisms allowing for the processing of non-symbolic quantities.

To address these questions, the scientists conducted a brain imaging experiment with 89 children either at the beginning (age 5) or four years into formal education (age 8). In a functional magnetic resonance imaging (fMRI) scanner, children were passively presented with series of dot arrays and Arabic digits. The scientists used a technique called machine-learning decoding to identify the brain representations of both dot arrays and digits in 5- and 8-year-olds. They also used the same technique to test whether identical brain mechanisms were representing dot arrays and digits in children, and whether this changed with age.

The results showed that Arabic digits and dot arrays were represented in a large network of cortical regions in both 5-year-olds and 8-year-olds. Most likely as a result of education, such representations significantly expanded from age 5 to age 8, notably in regions of the prefrontal cortex. Critically, machine-learning decoding notably revealed that a brain region in the parietal cortex was representing both dot arrays and digits in 5-year-olds. But this was no longer the case in 8-year-olds, for which brain networks for dot arrays and digits were largely segregated. These results suggest that children may harness evolutionary old mechanisms for non-symbolic quantity processing when beginning to learn symbols for numerical quantities. However, brain representations for symbolic quantities may become fully independent over the first years of formal math education. This suggests that, with education, number symbols may become progressively estranged from the non-symbolic numerical representations humans share with other animals. Overall, these results shed some light on the fundamental question of how number symbols get their meanings, i.e., the so-called symbol grounding problem.

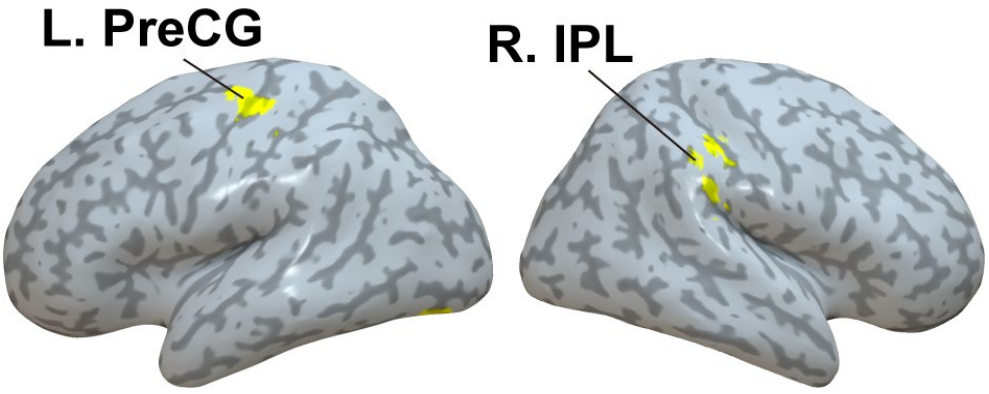

Figure: In 5-year-olds, the same regions of the right inferior parietal lobule (R. IPL) and left precentral gyrus (L. PreCG) represented both dot arrays and Arabic numerals (in yellow). This was no longer the case in 8-year-olds, who were using separate regions.

To go further:

Cortical representations of numbers and non-symbolic quantities expand and segregate in children from 5 to 8 years of age

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Contact:

Jérôme Prado
chercheur CNRS
jerome.prado@univ-lyon1.fr

Laboratory:

Centre de recherches en neurosciences de Lyon (CNRS/Inserm/Université de Lyon)
Centre hospitalier Le Vinatier,
Bâtiment 462 Neurocampus Michel Jouvet
95 boulevard Pinel
69500 Bron