Cerebral Cortex, 2025, **35**, bhaf207
https://doi.org/10.1093/cercor/bhaf207
Advance access publication date 1 August 2025
Commentary

The number sense: likely innate, surely not visual. *A commentary on "Is there an innate sense of number in the brain?"*

Ying Yang* and Olivier Collignon*

Institutes for Research in Neuroscience (IoNS) & Psychology (IPSY), University of Louvain (UCLouvain), Avenue Emmanuel Mounier, 53 – bte B1.53.02, B - 1200 Woluwé-Saint-Lambert, Belgium

*Corresponding authors: Ying Yang, Institutes for Research in Neuroscience (IoNS) & Psychology (IPSY), University of Louvain (UCLouvain), Avenue Emmanuel Mounier, 53 – bte B1.53.02, B - 1200 Woluwé-Saint-Lambert, Belgium. Email: yyangpsy@gmail.com; Olivier Collignon, Institutes for Research in Neuroscience (IoNS) & Psychology (IPSY), University of Louvain (UCLouvain), Avenue Emmanuel Mounier, 53 – bte B1.53.02, B - 1200 Woluwé-Saint-Lambert, Belgium. Email: olivier.collignon@uclouvain.be

Lorenzi et al. (2025) convincingly support the idea of an innate number sense. However, in their paper, and in most of the commentaries it triggered, authors assume that the number sense is visually grounded. We challenge this view based on two key arguments: the number sense is supramodal and can develop in congenitally blind people. Together, these points suggest that the number sense is a modality-independent faculty, accessible through any sensory and cognitive channels, with vision being just one convenient gateway among others.

Keywords: congenitally blind; numerosity; supramodal number sense.

Introduction

Lorenzi et al. (2025) offer compelling evidence that the number sense is innate. They support this claim with converging behavioral and neural findings from newborn animals suggesting a sensitivity for numerical information since birth, in the absence of specific training or experience. They for instance demonstrate that newly hatched chicks display a number sense immediately after birth when tested on visual display. However, the paper and most of the ensuing commentaries it triggered implicitly assume that the number sense is primarily visual in nature. This view is most explicitly expressed in Harvey's comment, in which it is suggested that the innate number sense is "an innate property of vision, derived from the spatial frequency-based representation of images in the visual systems" (Harvey 2025). According to this view, numerical representations emerge from the visual system's extraction of spatial frequency information in the environment. The early visual system is hard-wired to encode image contrast in the spatial frequency domain, and because the total frequency energy of an image correlates very closely with numerosity, numerosity can be straightforwardly derived by subsequent stages of processing (Paul et al. 2022; Harvey 2025).

While this visual-centric perspective offers a compelling low-level explanation of how the brain might extract numerical information from visual input, it raises an important question: Is vision truly a mandatory building block for the emergence of the number sense?

Vision indeed provides clear advantages in processing numerical information. It can simultaneously handle a large amount of information, while audition and touch are more limited to how much information they can process simultaneously (Anobile et al. 2016b). Perhaps one of the most striking (but debated; see Yousif et al. 2024) demonstrations of a visual number sense (as explicitly mentioned in the title of the original paper) relies on the observation that perceived numerosity is susceptible to adaptation, like any primary visual properties (Burr and Ross 2008). Visuospatial coding of numerosity is also supported by the SNARC effect, where participants respond faster when smaller numbers are associated with the left hand and larger numbers with the right (Dehaene et al. 1993; Gevers et al. 2006). Additionally, subitizing, the rapid and accurate enumeration of small sets, is commonly believed to rely on the visual system's capacity to index multiple objects in parallel (Kaufman et al. 1949; Dehaene and Cohen 1994).

However, we challenge the notion that the number sense is inherently based on vision relying on two key arguments: first, the supramodal nature of the number sense; and second, its development in individuals who have never had visual experience.

First, extensive evidence supports that the number sense relies on mechanisms that are not exclusive to the visual system. Numerical abilities have been well documented across auditory and tactile modalities (Tokita and Ishiguchi 2011; Arrighi et al. 2014; Yang et al. 2025). Individuals can estimate and compare numerical quantities as sequences of sounds or tactile stimuli. One might wonder whether numerical representations arising across different senses derive from similar mechanisms or instead arise independently—such that the representational format of the visual numerosity might be different from the one

Received: July 4, 2025. **Accepted:** July 7, 2025

in audition and touch. Several lines of evidence suggest that this is unlikely. First, numerical estimation and discrimination in touch and audition follow the same governing principles observed in vision, such as the distance effect (where numbers that are numerically closer are harder to discriminate) and the size effect (where larger numbers are harder to process) (Szűcs and Csépe 2005; Piazza et al. 2006; Krause et al. 2013). Second, the magnitude of the SNARC effect does not significantly differ across modalities, suggesting a shared underlying representational format (Crollen et al. 2013). Third, and maybe more convincingly, cross-modal adaptation studies show that adapting to numerical information in one sense has a repulsive perceptual effect on numerical estimation in another sense (Anobile et al. 2016a; Togoli and Arrighi 2021).

These observations immediately complicate explanations of numerosity that posit a direct link between visual experience and numerosity. The fact that numerosity arises in—and generalize across—audition, touch, as well as vision points to more fundamental origins than learned mapping from visual input.

One may however still argue that numerical estimation based on nonvisual information might depend on projecting nonvisual information onto a visual scaffold; vision would represent the developmental foundation on which other senses build on to develop a mature sense of number. However, the strongest argument against this idea comes from the studies of individuals who never had visual experience. If vision were essential for developing a number sense, congenitally blind individuals would show severely impaired numerical abilities (Crollen and Collignon 2020). Yet, numerous studies have shown that blind individuals perform similarly to, or even sometimes better than, sighted individuals in numerical tasks, including numerical estimation and arithmetic operations (Castronovo and Seron 2007; Dormal et al. 2016; Kanjlia et al. 2018). Blind individuals also exhibit the typical distance and size effects when perceiving numerosity through nonvisual modalities, suggesting that an analog number line can develop without visual calibration (Szűcs and Csépe 2005; Castronovo and Seron 2007). Similarly, they display a SNARC effect, indicating that spatial coding of number can emerge independently of vision (Crollen et al. 2013). Remarkably, subitizing—long thought to rely on the visual system's capacity for parallel item processing—has also been observed in blind individuals, suggesting that subitizing is a general mechanism rather than a vision-specific computation (Ferrand et al. 2010). Neuroimaging studies further support these behavioral observations by revealing that similar brain regions, particularly the intraparietal sulcus, are involved in numerical thinking in both congenitally blind and sighted individuals (Kanjlia et al. 2016; Crollen et al. 2019), with the additional engagement of dorsal occipital regions in blind people.

Actually, Lorenzi et al. mention that newly hatched chicks are exposed to proprioceptive sounds or tactile simulation before hatching, raising the intriguing possibility that nonvisual sensory input may support the early development of the number sense ("Innate" is considered as "existing from birth", which does not mean independent from experience - see Kevin Mitchell's book *Innate* for further development on the topic (Princeton University Press, 2018))). This idea converges with our proposition that vision might not be a prerequisite for the emergence of the number sense. Taken together, these arguments undermine the notion that the number sense develops based on visual experience. Instead, the number sense appears to be a modality-independent faculty that the brain can access through whichever sensory and cognitive channels are available, with vision merely one convenient gateway among many. By moving beyond a vision-centric perspective, the field of numerical cognition can gain deeper insights into the fundamental principles governing the (innate) emergence of the number sense.

Author contributions

Ying Yang (Writing—original draft, Writing—review & editing), Olivier Collignon (Writing—original draft, Writing—review & editing).

Funding

The project was funded in part by the Belgian Excellence of Science (EOS) program (Project No. 30991544) awarded to O.C. O.C. is a senior research associate at the Fond National de la Recherche Scientifique de Belgique (FRS-FNRS).

Conflict of interest statement: None declared.

References

Anobile G, Arrighi R, Togoli I, Burr DC. 2016a. A shared numerical representation for action and perception. *eLife*. 5:e16161. https://doi.org/10.7554/eLife.16161.001.

Anobile G, Cicchini GM, Burr DC. 2016b. Number as a primary perceptual attribute: a review. *Perception*. 45:5–31. https://doi.org/10.1177/0301006615602599.

Arrighi R, Togoli I, Burr DC. 2014. A generalized sense of number. *Proc R Soc B Biol Sci*. 281:1791. https://doi.org/10.1098/rspb.2014.1791.

Burr D, Ross J. 2008. A visual sense of number. *Curr Biol*. 18:425–428. https://doi.org/10.1016/j.cub.2008.02.052.

Castronovo J, Seron X. 2007. Numerical estimation in blind subjects: evidence of the impact of blindness and its following experience. *J Exp Psychol Hum Percept Perform*. 33:1089–1106.

Crollen V, Collignon O. 2020. How visual is the «number sense»? Insights from the blind. *Neurosci Biobehav Rev*. 118:290–297. https://doi.org/10.1016/j.neubiorev.2020.07.022.

Crollen V, Dormal G, Seron X, Lepore F, Collignon O. 2013. Embodied numbers: the role of vision in the development of number–space interactions. *Cortex*. 49:276–283. https://doi.org/10.1016/j.cortex.2011.11.006.

Crollen V et al. 2019. Recruitment of the occipital cortex by arithmetic processing follows computational bias in the congenitally blind. *NeuroImage*. 186:549–556. https://doi.org/10.1016/j.neuroimage.2018.11.034.

Dehaene S, Cohen L. 1994. Dissociable mechanisms of subitizing and counting: neuropsychological evidence from simultanagnosic patients. *J Exp Psychol Hum Percept Perform*. 20:958–975.

Dehaene S, Bossini S, Giraux P. 1993. The mental representation of parity and number magnitude. *J Exp Psychol Gen*. 122:371–396. https://doi.org/10.1037/0096-3445.122.3.371.

Dormal V, Crollen V, Baumans C, Lepore F, Collignon O. 2016. Early but not late blindness leads to enhanced arithmetic and working memory abilities. *Cortex*. 83:212–221. https://doi.org/10.1016/j.cortex.2016.07.016.

Ferrand L, Riggs KJ, Castronovo J. 2010. Subitizing in congenitally blind adults. *Psychon Bull Rev*. 17:840–845. https://doi.org/10.3758/PBR.17.6.840.

Gevers W, Verguts T, Reynvoet B, Caessens B, Fias W. 2006. Numbers and space: a computational model of the SNARC effect. *J Exp Psychol Hum Percept Perform*. 32:32–44.

Harvey B. 2025. Innate numerosity perception and its roots in early vision. *Cereb Cortex*. 35:bhaf016. https://doi.org/10.1093/cercor/bhaf016.

Kanjlia S, Lane C, Feigenson L, Bedny M. 2016. Absence of visual experience modifies the neural basis of numerical thinking. *Proc Natl Acad Sci USA*. 113:11172–11177. https://doi.org/10.1073/pnas.1524982113.

Kanjlia S, Feigenson L, Bedny M. 2018. Numerical cognition is resilient to dramatic changes in early sensory experience. *Cognition*. 179:111–120. https://doi.org/10.1016/j.cognition.2018.06.004.

Kaufman EL, Lord MW, Reese TW, Volkmann J. 1949. The discrimination of visual number. *Am J Psychol*. 62:498–525. https://doi.org/10.2307/1418556.

Krause F, Bekkering H, Lindemann O. 2013. A feeling for numbers: shared metric for symbolic and tactile numerosities. *Front Psychol*. 4:7. https://doi.org/10.3389/fpsyg.2013.00007.

Lorenzi E, Kobylkov D, Vallortigara G. 2025. Is there an innate sense of number in the brain? *Cereb Cortex*. 35:bhaf004. https://doi.org/10.1093/cercor/bhaf004.

Paul JM, van Ackooij M, ten Cate TC, Harvey BM. 2022. Numerosity tuning in human association cortices and local image contrast representations in early visual cortex. *Nat Commun*. 13:1340. https://doi.org/10.1038/s41467-022-29030-z.

Piazza M, Mechelli A, Price CJ, Butterworth B. 2006. Exact and approximate judgements of visual and auditory numerosity: an fMRI study. *Brain Res*. 1106:177–188. https://doi.org/10.1016/j.brainres.2006.05.104.

Szűcs D, Csépe V. 2005. The parietal distance effect appears in both the congenitally blind and matched sighted controls in an acoustic number comparison task. *Neurosci Lett*. 384:11–16. https://doi.org/10.1016/j.neulet.2005.04.050.

Togoli I, Arrighi R. 2021. Evidence for an A-modal number sense: numerosity adaptation generalizes across visual, auditory, and tactile stimuli. *Front Hum Neurosci*. 15:713565. https://www.frontiersin.org/articles/10.3389/fnhum.2021.713565.

Tokita M, Ishiguchi A. 2011. Temporal information affects the performance of numerosity discrimination: Behavioral evidence for a shared system for numerosity and temporal processing. *Psychon Bull Rev*. 18:550–556. https://doi.org/10.3758/s13423-011-0072-2.

Yang Y et al. 2025. Multifaceted brain representation of numerosity across the senses and presentation formats. *bioRxiv*. 2025.05.29.653470. https://doi.org/10.1101/2025May29.653470.

Yousif SR, Clarke S, Brannon EM. 2024. Number adaptation: a critical look. *Cognition*. 249:105813. https://doi.org/10.1016/j.cognition.2024.105813.

Cerebral Cortex, 2025, **35**, bhaf207
https://doi.org/10.1093/cercor/bhaf207
Commentary