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Perceiving numerosity from birth

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theory. It takes the form of a developmental scenario, whereby numerical competence emerges from learning “the correlation between numerosity and continuous magnitudes.”

There are at least two logical flaws with this view. The first is its circularity. Capturing the correlation between numerosity and other dimensions requires representing numerosity in the first place. The authors acknowledge it and simply propose that number words would serve to trigger the emergence of numerosity. But how would number words make contact with numerosities? No answer is offered. The second and even more serious issue is that it is unclear whether continuous dimensions are sufficient to extract a representation of number, because the natural correlations between numerosity and continuous magnitudes even if most often present, are not stable in the world (see Figure 1). Sometimes numerosity could be predicted from contour area rather than occupancy, and sometimes it is the other way round. Therefore, whereas multiple cues may serve as proxies to order collections by numerosity, it is unclear how they could subserve the *estimation* of number.

To conclude, we would argue that a minimal requirement for future theoretical endeavours about numerosity processing would be to seriously consider and implement distinctions between the mechanism of numerosity extraction, the format of numerosity representation, and the decision processes that are required to perform a given task. That (some) continuous magnitudes would be extracted and combined in some weighted average to deliver a representation of number is one logical possibility. How the weights are determined without reference to numerosity remains, however, to be clarified. Yet another possibility would be that continuous magnitude information only affects late decision stages. Other scenarios are also possible, and we believe, more plausible. One is a specific, direct, numerosity extraction mechanism based on sampling the visual scene for individual elements feeding into a common magnitude representation system (see Cantlon et al. 2009b).

Perceiving numerosity from birth

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Abstract: Leibovich et al. opened up an important discussion on the nature and origins of numerosity perception. The authors rightly point out that non-numerical features of stimuli influence this ability. Despite these biases, there is evidence that from birth, humans perceive and represent numerosities, and not just non-numerical quantitative features such as item size, density, and convex hull.

Although it is impossible to simultaneously control for all continuous quantities in a single numerosity display, some studies have developed ingenious designs controlling these variables across all of the experiment’s displays, as for example in Xu and Spelke’s (2000) seminal study. Six-month-old infants saw first several arrays of a fixed numerosity (either 8 or 16, in different groups), varying in dot size and position. Once habituated, all infants were tested with two numerosities in alternation (8 and 16). Crucially, different aspects of stimuli were controlled in the habituation and test phases: the summed area of all dots (as well as brightness and contour length) and the array area were matched on average between the 8 and 16 habituation groups, while the density and dot size were matched between the two tested numerosities. Therefore, if infants attend to dot size or density, they will respond in the same way to test numerosities 8 and 16; whereas if infants attend to summed area or array area, the two groups will respond similarly to the test stimuli. Sensitivity to non-numerical parameters, either a single parameter or a combination of them, thus cannot explain the interaction pattern observed: In both groups, infants looked longer at the novel numerosity. This finding has been replicated by a different group (Brannon et al. 2004), using different numerical values (Xu 2003), in the auditory modality (Lipton & Spelke 2003), and the same parameter control strategy was employed to demonstrate sensitivity to numerosity at the brain level (Izard et al. 2008, Piazza et al. 2004).

Similar controls for non-numerical features were used to demonstrate newborns’ sensitivity to number (Izard et al. 2009). While hearing a fixed value of numerosity (e.g., 12), newborns looked longer to arrays matched in numerosity than to non-matching arrays (e.g., 4). Because the stimuli were presented across two different modalities (auditory and visual), the newborns’ response was necessarily based on an abstract property of the stimuli. Following the logic of Xu and Spelke (2000), extensive parameters were controlled in the auditory stimuli across the two groups by equating the duration, and intensive parameters across the two test numerosities in the visual modality by equating density and item size. Therefore, infants’ preference for the matching stimuli could be explained only by numerosity, not by sensitivity to an abstract notion of amount, or rate. Moreover, as infants received only one numerosity in the auditory modality, they could not be responding to relative quantity (“more” or “less”). In that respect, the numerosity paradigm departed crucially from another paradigm used later (de Hevia et al. 2014), in which newborns matched two values, one small and one large, across the two dimensions of numerosity and spatial extent. Newborns are able to relate increases versus decreases of quantities at a generic level, but also to perceive numerosities, calibrated across senses.

In line with these findings, studies investigating newborns’ visual perception have demonstrated that they are able to represent individual objects, at the same age as in the numerosity study. In particular, human newborns can perceive complete shapes over partial occlusion (Valenza et al. 2006), and they can both distinguish individual elements of a stimulus or group them into a holistic percept (Antell and Caron 1985, Farroni et al. 2000, Turati et al. 2013). Moreover, newborns respond differently to faces displaying direct versus averted gaze (Guellai & Streri 2011), a much finer cue than the shapes used in the numerosity experiment. Perceptual abilities to individuate items from the background and from one another likely fed into the numerosity percept evidenced by Izard et al.’s (2009) study.

Despite the common belief that numerosity perception must be more complex, and therefore a later developmental achievement, than the perception of continuous quantity, developmental studies have provided evidence that numerosity discrimination is easier and more automatic. In particular, infants show higher sensitivity to, and prefer to look at, changes in numerosity over changes in item or total surface area, when difference ratios are equated across dimensions (Brannon et al. 2004; Cordes & Brannon 2008; 2011), and even when variations in number are smaller (Libertus et al. 2014). Similarly, children show higher sensitivity to number than to density (Anobile et al. 2016b). That perception of numerosity is more automatic than other continuous quantities is true in adults too: Even without an explicit task,

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numerosity of visual arrays is processed faster than other continuous features of those arrays (Park et al. 2016b). In this context, it is important to note that although Stroop studies on adults indicate that continuous quantities interfere with number perception, much of the behavioral and neuroscientific evidence cited by Leibovich et al. is based on interference paradigms in which non-numerical quantities varied by considerably larger ratios (and, thus, likely had higher perceptual discriminability and salience) than numerosity.

At the brain level, areas in the intraparietal sulcus respond to numerosity, and not simply to non-numerical cues. In particular, Eger et al. (2009) used intraparietal sulcus activations to train a classifier to discriminate between patterns evoked by different numerosities across which item size was equated and found that this classifier generalized without accuracy loss to patterns evoked by numerosities across which total surface area was equated (and vice versa). Numerosity was also decodable from the intraparietal sulcus when low-level factors such as contrast energy were equated (Castaldi et al. 2016). Finally, in the right superior parietal lobe Harvey et al. (2013) observed an orderly topographical structure of numerosity responses, correlated across stimulus sets implementing different controls. Although the same region also responds to object size (Harvey et al. 2015), the tuning curves and map organization differ, thus highlighting the specificity of the numerosity response.

In summary, the literature brings uncontroversial evidence that humans perceive and represent numerosity from birth on. As pointed out by Leibovich et al., the literature also brings uncontroversial evidence that numerosity perception is imperfect, often subject to the influence of non-numerical aspects of stimuli. These phenomena are fascinating, as they open up a new research agenda – if perception of numerosity relies on an imperfect algorithm, we now need to crack up its functioning.

Multitudes are adaptable magnitudes in the estimation of number

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Abstract: Visual number comparison does not require participants to choose a unit, whereas units are fundamental to the definition of number. Studies using magnitude estimation rather than comparison show that number perception is compressed dramatically past about 20 units. Even estimates of 5–20 items are increasingly susceptible to effects of visual adaptation, suggesting a rather narrow range in which subitizing-like categorization processes blend into greater reliance on adaptable magnitude information.

When people perceive a collection as having an amount, do they assign a conceptual category (number) to something that is experienced as a multitude of units, or is that conceptualization dependent on language? In Book 7 of Euclid's *Elements* (300 BC/1956), Euclid famously defined a number as "a multitude of units" after having defined a unit, quite wonderfully, as "that by virtue of which each of the things that exist is called one" (p. 277). Leibovich et al. propose that whether nervous systems treat perceptual number as a multitude rather than a magnitude may be unknowable because perceived number cannot be isolated from all confounding perceptual continuous magnitudes that are typically correlated with number. But multiple information-processing systems in perception might work together to help obviate this concern. Here I consider how the fragile boundary between magnitudes and multitudes might be manifest in numerosity estimation.

Unlike most perceptual magnitudes (loudness, area, brightness), numerosity has a built in unit. To compare the numbers of two collections is to try to identify a relative quantity of units. For small collections of two or three, special geometrical or attention processes may differentiate categories, but for large numbers, clearly any estimate must be an approximation. Is it simply a sensed magnitude? There is evidence that even a collection as small as five fails to form a discriminable numeric category in human adults in the absence of linguistic labels (Gordon 2004).

For some, the adaptability of visually perceived number is to strongly suggest that large visual number is estimated based on correlated features (Durgin 1995). How else could 200 dots appear perceptually equivalent to 400 dots? It could not be that some of the dots are missing. Rather, some visual property is clearly being adapted, and locally rescaled, and that property seems to act like a continuous magnitude (like brightness, loudness, etc.). Durgin argued that effects of adaptation produced multiple visual consequences including the underestimation of apparent numerosity – which was most pronounced for high numbers (in the hundreds), but also changes in perceived spacing or distribution. Adaptation, like number comparison, provides no obvious way to unconfound number, except insofar as adaptation fails (i.e., true number triumphs).

Number comparisons may be thought of as comparing several visual magnitudes correlated with numerosity (including area, Allik & Tuulmets [1991], and density). Whereas Anobile et al. (2014) sought to distinguish between number perception and density perception using differential Weber fractions, as Leibovich et al. point out, even distinguishing two distinct sources of judgment does not show that either one of them is number itself.

Still, the existence of multiple sources of information relevant to estimating numbers does not show that number perception does not occur. Having multiple sources of information about depth that get combined into a common perceptual estimate does not mean that we do not perceive depth, but it is hard to infer the information content of perceptual experience solely from discriminations tasks or categorization tasks.

An alternative approach to studying number with humans is to use magnitude estimation rather than magnitude discrimination. That is, human participants who have a linguistic number system can estimate how many units are present, just as they can estimate other psychophysical properties. Studies by Krueger (1972) and by Kaufman et al. (1949) have shown that dot collections as high as 200 dots are grossly underestimated, suggesting that "number" is (under) estimated rather than sensed for numbers of this magnitude. Perhaps this is just a translation problem of converting perceptions into words or maybe approximate "number" perception is just an adaptable continuous magnitude that humans conceptualize as being composed of units.

Alex Huk and I (Durgin 2016; Huk & Durgin 1996) tested how density adaptation affects number estimation. Participants who were adapted to dense texture to one side of fixation were briefly shown either one field of dots on one side or the other, or two fields of dots (one on each side). When only one field was flashed, they reported its apparent numerosity; when both fields flashed, they were to indicate which side appeared more numerous. The effect of adaptation on numerosity comparison was stronger as numerosity increased, and a similar pattern emerged for numerosity estimation.

The estimation data are shown in Figure 1. Number estimates were unaffected for 5 dots. But for more numerous collections (40 dots or more), estimates were about 25% lower in retinotopic regions adapted to dense (high numerosity) random dots fields than in unadapted regions. The average estimate for 256 actual dots, for example, was 154 in the unadapted region, and only 117 in the adapted region. Significantly, the numerosity estimation functions shown here in log-log space seem to bend significantly between 20 and 40 dots.

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model and look forward to seeing what future studies will bring.

NOTES

1. Tali Leibovich and Naama Katzin contributed equally to this work.

2. Maayan Harel was not available to contribute to the Response article and did not participate in writing it. Moti Salti was not involved in writing the target article, but contributed to the Response article and participated in writing it.

References

[The letters "a" and "r" before author's initials stand for target article and response references, respectively]

Abbas, F. & Meyer, M. P. (2014) Fish vision: Size selectivity in the zebrafish retinotectal pathway. *Current Biology* 24(21):R1048–50. doi: 10.1016/j.cub.2014.09.043. [aTL]

Abreu-Mendoza, R. A. & Arias-Trejo, N. (2015) Numerical and area comparison abilities in Down syndrome. *Research in Developmental Disabilities* 41–42:58–65. doi: 10.1016/j.ridd.2015.05.008. [aTL]

Agrillo, C., Dadda, M., Serena, G. & Bisazza, A. (2008) Do fish count? Spontaneous discrimination of quantity in female mosquitofish. *Animal Cognition* 11(3):495–503. doi: 10.1007/s10071-008-0140-9. [aTL, CA]

Agrillo, C., Dadda, M., Serena, G. & Bisazza, A. (2009) Use of number by fish. *PLoS ONE* 4(3):e4786. doi: 10.1371/journal.pone.0004786. [aTL, CA]

Agrillo, C., Petrazzini, M. E. M. & Bisazza, A. (2016) Number vs. continuous quantities in lower vertebrates. In: Continuous issues in numerical cognition, ed. A. Henik, pp. 149–74. Elsevier. doi: 10.1016/B978-0-12-801637-4.00007-X. [aTL]

Agrillo, C., Piffer, L. & Bisazza, A. (2011) Number versus continuous quantity in numerosity judgments by fish. *Cognition* 119:281–87. [CA]

Agrillo, C., Piffer, L., Bisazza, A. & Butterworth, B. (2012) Evidence for two numerical systems that are similar in humans and guppies. *PLoS ONE* 7(2): e31923. doi: 10.1371/journal.pone.0031923. [IPS]

Agrillo, C., Piffer, L., Bisazza, A. & Butterworth, B. (2015) Ratio dependence in small number discrimination is affected by the experimental procedure. *Frontiers in Psychology* 6:1649. doi: 10.3389/fpsyg.2015.01649. [aTL]

Aguirre, G. K., Zarahn, E. & D'esposito, M. (1998) An area within human ventral cortex sensitive to "building" stimuli: Evidence and implications. *Neuron* 21 (2):373–83. [NG]

Allik, J. & Tuulmets, T. (1991) Occupancy model of perceived numerosity. *Perception & Psychophysics* 49:303–14. [FHD, TG, IPS]

Allik, J. & Tuulmets, T. (1993) Perceived numerosity of spatiotemporal events. *Perception & Psychophysics* 53(4):450–59. doi: 10.3758/bf03206789. [JP]

Amso, D. & Scerif, G. (2015) The attentive brain: Insights from developmental cognitive neuroscience. *Nature Reviews Neuroscience* 16(10):606–19. [RM]

Anderson, P. (2002) Assessment and development of executive function (EF) during childhood. *Child Neuropsychology* 8(2):71–82. [DS]

Anobile, G., Arrighi, R., Togoli, I. & Burr, D. C. (2016a) A shared numerical representation for action and perception. *Elife* 5:e16161. doi: 10.7554/eLife.16161. [DCB]

Anobile, G., Castaldi, E., Turi, M., Tinelli, F. & Burr, D. C. (2016b) Numerosity but not texture-density discrimination correlates with math ability in children. *Developmental Psychology* 52(8):1206–16. doi: 10.1037/dev0000155. [DCB, MDdH]

Anobile, G., Cicchini, G. M. & Burr, D. C. (2014) Separate mechanisms for perception of numerosity and density. *Psychological Science* 25(1):265–70. doi: 10.1177/0956797613501520. [FHD, DO]

Anobile, G., Cicchini, G. M. & Burr, D. C. (2016c) Number as a primary perceptual attribute: A review. *Perception* 45(1–2):5–31. doi: 10.1177/0301006615602599. [DCB, AC, AN]

Antell, S. E. & Caron, A. J. (1985) Neonatal perception of spatial relationships. *Infant Behavior and Development* 8(1):15–23. [MDdH]

Antell, S. E. & Keating, D. P. (1983) Perception of numerical invariance in neonates. *Child Development* 54:695–701. [KSM]

Arrighi, R., Togoli, I. & Burr, D. C. (2014) A generalized sense of number. *Proceedings of the Royal Society B* 281:20141791. Available at: http://dx.doi.org/10.1098/rspb.2014.1791 [DCB]

Ashkenazi, S., Mark-Zigdon, N. & Henik, A. (2013) Do subitizing deficits in developmental dyscalculia involve pattern recognition weakness? *Developmental Science* 16(1):35–46. doi: 10.1111/j.1467-7687.2012.01190.x. [aTL]

Atkinson, J. & Braddick, O. (1992) Visual segmentation of oriented textures by infants. *Behavioural Brain Research* 49:123–31. [SFL]

Atkinson, J., Braddick, O. & Braddick, F. (1974) Acuity and contrast sensitivity of infant vision. *Nature* 247:403–404. [SFL]

Baillargeon, R. (1994) How do infants learn about the physical world? *Current Directions in Psychological Science* 3(5):133–40. [KSM]

Baldwin, D. A. (1993) Early referential understanding: Infants' ability to recognize referential acts for what they are. *Developmental Psychology* 29(5):832–43. doi: 10.1037/0012-1649.29.5.832. [rTL]

Banks, M. S. (1980) The development of visual accommodation during early infancy. *Child Development* 51(3):646–66. [aTL]

Banks, M. S. & Salapatek, P. (1981) Infant pattern vision: A new approach based on the contrast sensitivity function. *Journal of Experimental Child Psychology* 31:1–45. [SFL]

Barth, H., Kanwisher, N. & Spelke, E. (2003) The construction of large number representations in adults. *Cognition* 86(3):201–21. doi: 10.1016/S0010-0277(02)00178-6. [aTL]

Barth, H., La Mont, K., Lipton, J. & Spelke, E. S. (2005) Abstract number and arithmetic in preschool children. *Proceedings of the National Academy of Sciences of the United States of America* 102(39):14116–21. Available at: http://www.pnas.org/content/102/39/14116.short. [aTL, AN]

Barth, H. C. (2008) Judgments of discrete and continuous quantities: An illusory Stroop effect. *Cognition* 109:251–66. [SS]

Barth, H. C. & Paladino, A. M. (2011) The development of numerical estimation: Evidence against a representational shift. *Developmental Science* 14(1):125–35. doi: 10.1111/j.1467-7687.2010.00962.x. [PGS]

Behrmann, M. & Plaut, D. C. (2013) Distributed circuits, not circumscribed centers, mediate visual recognition. *Trends in Cognitive Sciences* 17(5):210–19. [NG]

Behrmann, M. & Plaut, D. C. (2014) Bilateral hemispheric processing of words and faces: Evidence from word impairments in prosopagnosia and face impairments in pure alexia. *Cerebral Cortex* 24:1102–18. doi: 10.1093/cercor/bhs390. [NG]

Beran, M. J. (2007) Rhesus monkeys (*Macaca mulatta*) enumerate large and small sequentially presented sets of items using analog numerical representations. *Journal of Experimental Psychology: Animal Behavior Processes* 33:42–54. [aTL, MJB]

Beran, M. J. (2012) Quantity judgments of auditory and visual stimuli by chimpanzees (*Pan troglodytes*). *Journal of Experimental Psychology: Animal Behavior Processes* 38:23–29. [MJB]

Beran, M. J., Evans, T. A., Leighty, K., Harris, E. H. & Rice, D. (2008) Summation and quantity judgment of simultaneously and sequentially presented sets by capuchin monkeys (*Cebus apella*). *American Journal of Primatology* 70:191–94. [MJB]

Beran, M. J. & Parrish, A. E. (2016) Going for more: Discrete and continuous quantity judgments by nonhuman animals. In: *Continuous issues in numerical cognition: How many or how much*, ed. A. Henik, pp. 175–92. Academic Press. [MJB]

Beran, M. J., Parrish, A. E. & Evans, T. A. (2015a) Numerical cognition and quantitative abilities in nonhuman primates. In: *Evolutionary origins and early development of number processing*, ed. D. Geary, D. Berch & K. Mann Koepke, pp. 91–119. Elsevier. [MJB]

Beran, M. J., Perdue, B. M. & Evans, T. A. (2015b) Monkey mathematic al abilities. In: *Oxford handbook of mathematical cognition*, ed. R. Cohen Kadosh & A. Dowker, pp. 237–257. Oxford University Press. [MJB]

Beran, M. J. & Rumbaugh, D. M. (2001) "Constructive" enumeration by chimpanzees (*Pan troglodytes*) on a computerized task. *Animal Cognition* 4:81–89. [MJB]

Binda, P., Morrone, M. C. & Bremmer, F. (2012) Saccadic compression of symbolic numerical magnitude. *PLoS ONE* 7(11):e49587. doi: 10.1371/journal.pone.0049587. [DCB]

Bisazza, A., Serena, G., Piffer, L. & Agrillo, C. (2010) Ontogeny of numerical abilities in guppies. *PLoS ONE* 5(11):e15516. [CA]

Blair, C. & Razza, R. P. (2007) Relating effortful control, executive function, and false belief understanding to emerging math and literacy ability in kindergarten. *Child Development* 78(2):647–63. doi: 10.1111/j.1467-8624.2007.01019.x. [aTL]

Bogale, B. A., Kamata, N., Mioko, K. & Sugita, S. (2011) Quantity discrimination in jungle crows, *Corvus macrorhynchos*. *Animal Behaviour* 82(4):635–41. doi: 10.1016/j.anbehav.2011.05.025. [aTL]

Bonny, J. W. & Lourenco, S. F. (2013) The approximate number system and its relation to early math achievement: Evidence from the preschool years. *Journal of Experimental Child Psychology* 114(3):375–88. doi: 10.1016/j.jecp.2012.09.015. [aTL]

Bonny, J. W. & Lourenco, S. F. (in preparation) The impact of spatial context of nonsymbolic number and cumulative area judgments. [SFL]

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Borensztajn, G., Zuidema, W. & Bod, R. (2009) Children’s grammars grow more abstract with age—Evidence from an automatic procedure for identifying the productive units of language. *Topics in Cognitive Science* 1:175–88. [WvW]

Boysen, S. T. & Berntson, G. G. (1989) Numerical competence in a chimpanzee (*Pan troglodytes*). *Journal of Comparative Psychology* 103:23–31. [MJB]

Brannon, E. M., Abbott, S. & Lutz, D. J. (2004) Number bias for the discrimination of large visual sets in infancy. *Cognition* 93(2):B59–68. doi: 10.1016/j.cognition.2004.01.004. [MDdH, SS]

Brannon, E. M. & Terrace, H. S. (1998) Ordering of the numerosities 1 to 9 by monkeys. *Science* 282(5389):746–49. [AN, IPS]

Brannon, E. M. & Terrace, H. S. (2000) Representation of the numerosities 1–9 by rhesus macaques (*Macaca mulatta*). *Journal of Experimental Psychology: Animal Behavior Processes* 26:31–49. [MJB]

Brass, M., Ullsperger, M., Knoesche, T. R., von Cramon, D. Y. & Phillips, N. A. (2005) Who comes first? The role of the prefrontal and parietal cortex in cognitive control. *Journal of Cognitive Neuroscience* 17(9):1367–75. doi: 10.1162/0898929054985400. [aTL]

Brown, A. M. & Yamamoto, M. (1986) Visual acuity in newborn and preterm infants measured with grating acuity cards. *American Journal of Ophthalmology* 102:245–53. [SFL]

Brown, S. W. (1995) Time, change, and motion: The effects of stimulus movement on temporal perception. *Perception and Psychophysics* 57(1):105–16. [DCB]

Bugden, S. & Ansari, D. (2016) Probing the nature of deficits in the ‘approximate number system’ in children with persistent developmental dyscalculia. *Developmental Science* 19(5):817–33. doi: 10.1111/desc.12324. [arTL, IPS]

Bull, R., Espy, K. A. & Wiebe, S. A. (2008) Short-term memory, working memory, and executive functioning in preschoolers: Longitudinal predictors of mathematical achievement at age 7 years. *Developmental Neuropsychology* 33(3):205–28. doi: 10.1080/87565640801982312. [aTL]

Bull, R. & Scerif, G. (2001) Executive functioning as a predictor of children’s mathematics ability: Inhibition, switching, and working memory. *Developmental Neuropsychology* 19(3):273–93. Available at: http://www.tandfonline.com/doi/abs/10.1207/ S15326942DN1903_3#.Va-zhUNVhBd. [aTL]

Burr, D. & Ross, J. (2008) A visual sense of number. *Current Biology* 18(6):425–28. doi: 10.1016/j.cub.2008.02.052. [aTL, AN, DO, IPS]

Burr, D. C. & Ross, J. (1986) Visual processing of motion. *Trends in Neurosciences* 9:304–307. doi: 10.1016/0166-2236(86)90088-3. [DCB]

Burr, D. C., Ross, J., Binda, P. & Morrone, M. C. (2010) Saccades compress space, time and number. *Trends in Cognitive Sciences* 14(12):528–33. doi: 10.1016/j.tics.2010.09.005. [DCB]

Burr, D. C. & Thompson, P. (2011) Motion psychophysics: 1985–2010. *Vision Research* 51(13):1431–56. doi:10.1016/j.visres.2011.02.008. [DCB]

Butterworth, B. (1999) Perspectives: Neuroscience – A head for figures. *Science* 284(5416):928–29. doi: 10.1126/science.284.5416.928. [NCJ]

Butterworth, B. (2005) The development of arithmetical abilities. *Journal of Child Psychology and Psychiatry* 46(1):3–18. doi: 10.1111/j.1469-7610.2004.00374.x. [NCJ]

Butterworth, B. & Reigosa-Crespo, V. (2007) Information processing deficits in dyscalculia. In: *Why is math so hard for some children? The nature and origins of mathematical learning difficulties and disabilities*, ed. D. B. Berch & M. M. M. Mazzocco, pp. 107–20. Paul H. Brookes. [NCJ]

Calhoun, L. G. (1971) Number conservation in very young children: The effect of age and mode of responding. *Child Development* 42(2):561–72. doi: 10.2307/1127488. [rTL]

Calton, J. L. & Taube, J. S. (2009) Where am I and how will I get there from here? A role for posterior parietal cortex in the integration of spatial information and route planning. *Neurobiology of Learning and Memory* 91(2):186–96. doi: 10.1016/j.nlm.2008.09.015. [aTL]

Calvert, G. A., Campbell, R. & Brammer, M. J. (2000) Evidence from functional magnetic resonance imaging of crossmodal binding in the human heteromodal cortex. *Current Biology* 10(11):649–57. doi: 10.1016/S0960-9822(00)00513-3. [aTL]

Cantlon, J. F. & Brannon, E. M. (2006) Shared system for ordering small and large numbers in monkeys and humans. *Psychological Science* 17(5):401–406. doi: 10.1111/j.1467-9280.2006.01719.x. [aTL]

Cantlon, J. F. & Brannon, E. M. (2007) How much does number matter to a monkey (*Macaca mulatta*)? *Journal of Experimental Psychology: Animal Behavior Processes* 33:32–41. [MJB]

Cantlon, J. F., Brannon, E. M., Carter, E. J. & Pelphrey, K. A. (2006) Functional imaging of numerical processing in adults and 4-y-old children. *PLoS Biology* 4(5):e125. doi: 10.1371/journal.pbio.0040125. [aTL]

Cantlon, J. F., Libertus, M. E., Pinel, P., Dehaene, S., Brannon, E. M. & Pelphrey, K. A. (2009a) The neural development of an abstract concept of number. *Journal of Cognitive Neuroscience* 21(11):2217–29. doi: 10.1162/jocn.2008.21159. [aTL]

Cantlon, J. F., Platt, M. L. & Brannon, E. M. (2009b) Beyond the number domain. *Trends in Cognitive Sciences* 13(2):83–91. doi: 10.1016/j.tics.2008.11.007. [arTL, MJB, AC]

Cantrell, L., Boyer, T. W., Cordes, S. & Smith, L. B. (2015a) Signal clarity: An account of the variability in infant quantity discrimination tasks. *Developmental Science* 18(6):877–93. doi: 10.1111/desc.12283. [KSM, SS]

Cantrell, L., Kuwabara, M. & Smith, L. B. (2015b) Set size and culture influence children’s attention to number. *Journal of Experimental Child Psychology* 131:19–37. doi: 10.1016/j.jecp.2014.10.010. [arTL, RM]

Cantrell, L. & Smith, L. B. (2013) Open questions and a proposal: A critical review of the evidence on infant numerical abilities. *Cognition* 128(3):331–52. doi: 10.1016/j.cognition.2013.04.008. [aTL, DCH, KSM, DO, JEO, SFL]

Cappelletti, M., Didino, D., Stoianov, I. & Zorzi, M. (2014) Number skills are maintained in healthy ageing. *Cognitive Psychology* 69:25–45. doi: 10.1016/j.cogpsych.2013.11.004. [IPS]

Cappelletti, M., Gessaroli, E., Hithersay, R., Mitolo, M., Didino, D., Kanai, R., Cohen Kadosh, R. & Walsh, V. (2013) Transfer of cognitive training across magnitude dimensions achieved with concurrent brain stimulation of the parietal lobe. *Journal of Neuroscience* 33(37):14899–907. doi: 10.1523/JNEUROSCI.1692-13.2013. [aTL]

Carey, S. (2001) Cognitive foundations of arithmetic: Evolution and ontogenisis. *Mind & Language* 16(1):37–55. doi: 10.1111/1468-0017.00155. [aTL, DCH, EM, RM]

Carey, S. (2009) Where our number concepts come from. *Journal of Philosophy* 106:220–54. [DS]

Carey, S. & Xu, F. (2001) Infants’ knowledge of objects: Beyond object files and object tracking. *Cognition* 80:179–213. [SFL]

Castaldi, E., Aagten-Murphy, D., Tosetti, M., Burr, D. & Morrone, M. C. (2016) Effects of adaptation on numerosity decoding in the human brain. *NeuroImage* 143:364–77. [MDdH]

Castelli, F., Glaser, D. E. & Butterworth, B. (2006) Discrete and analogue quantity processing in the parietal lobe: A functional MRI study. *Proceedings of the National Academy of Sciences of the United States of America* 103(12):4693–98. doi: 10.1073/pnas.0600444103. [aTL, AN]

Chao, L. L., Haxby, J. V. & Martin, A. (1999) Attribute-based neural substrates in temporal cortex for perceiving and knowing about objects. *Nature Neuroscience* 2(10):913–19. [NG]

Chassy, P. & Grodd, W. (2012) Comparison of quantities: Core and format-dependent regions as revealed by fMRI. *Cerebral Cortex* 22(6):1420–30. doi: 10.1093/cercor/bhr219. [aTL]

Chen, Q. & Li, J. (2014) Association between individual differences in non-symbolic number acuity and math performance: A meta-analysis. *Acta Psychologica* 148:163–72. [MI]

Cicchini, G. M., Anobile, G. & Burr, D. C. (2016) Spontaneous perception of numerosity in humans. *Nature Communications* 7:12536. doi: 10.1038/ncomms12536. [DCB, AC, AN, rTL]

Clarke, B. & Shinn, M. R. (2004) A preliminary investigation into the identification and development of early mathematics curriculum-based measurement. *School Psychology Review* 33(22):234–48. [NCJ]

Clayton, S. & Gilmore, C. (2015) Inhibition in dot comparison tasks. *ZDM Mathematics Cognition* 47:759–70. doi: 10.1007/s11858-014-0655-2. [aTL]

Clayton, S., Gilmore, C. & Inglis, M. (2015) Dot comparison stimuli are not all alike: The effect of different visual controls on ANS measurement. *Acta Psychologica* 161:177–84. doi: 10.1016/j.actpsy.2015.09.007. [arTL]

Clearfield, M. W. & Mix, K. S. (1999) Number versus contour length in infants’ discrimination of small visual sets. *Psychological Science* 10:408–11. [RR]

Clearfield, M. W. & Mix, K. S. (2001) Infants use continuous quantity – not number – to discriminate small visual sets. *Journal of Cognition and Development* 2:243–60. [RR]

Cleland, A. A. & Bull, R. (2015) The role of numerical and non-numerical cues in nonsymbolic number processing: Evidence from the line bisection task. *Quarterly Journal of Experimental Psychology* 68(9):1844–59. doi: 10.1080/17470218.2014.994537. [rTL]

Cohen Kadosh, K., Cohen Kadosh, R., Dick, F. & Johnson, M. H. (2010) Developmental changes in effective connectivity in the emerging core face network. *Cerebral Cortex* 21:1389–94. doi: 10.1093/cercor/bhq215. [NG]

Cohen Kadosh, R., Lammertyn, J. & Izard, B. (2008) Are numbers special? An overview of chronometric, neuroimaging, developmental and comparative studies of magnitude representation. *Progress in Neurobiology* 84(2):132–47. doi: 10.1016/j.pneurobio.2007.11.001. [aTL]

Cohen Kadosh, R. & Walsh, V. (2008) From magnitude to natural numbers: A developmental neurocognitive perspective. *Behavioral and Brain Sciences* 31(6):647–48. doi: 10.1017/S0140525X08005621. [aTL]

Connolly, A. C., Guntupalli, J. S., Gors, J., Hanke, M., Halchenko, Y. O., Wu, Y. C., Abdi, H. & Haxby, J. V. (2012) The representation of biological classes in the human brain. *Journal of Neuroscience* 32:2608–18. [NG]

Content, A. & Nys, J. (2016) The distribution game: Evidence for discrete numerosity coding in preschool children. In: *Continuous issues in numerical cognition*, ed. A. Henik, pp. 215–44. Elsevier. doi: 10.1016/B978-0-12-801637-4.00010-X. [AC]

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Cordes, S. & Brannon, E. M. (2008) The difficulties of representing continuous extent in infancy: Using number is just easier. *Child Development* 79(2):476–89. doi: 10.1111/j.1467-8624.2007.01137.x. [MDdH, MEL, SS]

Cordes, S. & Brannon, E. M. (2009) The relative salience of discrete and continuous quantity in young infants. *Developmental Science* 12(3):453–63. doi: 10.1111/j.1467-7687.2008.00781.x. [SFL, SS]

Cordes, S. & Brannon, E. M. (2011) Attending to one of many: When infants are surprisingly poor at discriminating an item's size. *Frontiers in Psychology* 2:65. doi: 10.3389/fpsyg.2011.00065. [MDdH, SFL, SS]

Coubart, A., Streri, A., de Hevia, M. D., Izard, V. (2015) Crossmodal discrimination of 2 vs. 4 objects across touch and vision in 5-month-old infants. *PLoS ONE* 10(3):e0120868. doi: 10.1371/journal.pone.0120868. [rTL]

Cragg, L. & Gilmore, C. (2014) Skills underlying mathematics: The role of executive function in the development of mathematics proficiency. *Trends in Neuroscience and Education* 3(2):63–68. doi: 10.1016/j.tine.2013.12.001. [aTL]

Dakin, S. C., Tibber, M. S., Greenwood, J. A., Kingdom, F. A. A. & Morgan, M. J. (2011) A common visual metric for approximate number and density. *Proceedings of the National Academy of Sciences of the United States of America* 108(49):19552–57. doi: 10.1073/Pnas.1113195108. [DCB, DO, IPS]

Dantzig, T. (1930) *Number: The language of science*. The Free Press. [AN]

Davidson, K., Eng, K. & Barner, D. (2012) Does learning to count involve a semantic induction? *Cognition* 123:162–73. [DS]

Davis, H. & Memmott, J. (1982) Counting behavior in animals: A critical evaluation. *Psychological Bulletin* 92:547–71. [MJB]

Davis, H. & Perusse, R. (1988) Numerical competence in animals: Definitional issues, current evidence and a new research agenda. *Behavioral and Brain Sciences* 11:561–79. [CA]

De Boysson-Bardies, B. (1993) Ontogeny of language-specific syllabic productions. In: *Developmental neurocognition: Speech and face processing in the first year of life*, ed. B. De Boysson-Bardies, S. de Schonen, P. Jusczyk, P. MacNeilage & J. Morton, pp. 353–63. Kluwer. [OR]

de Hevia, M. D., Girelli, L., Bricolo, E., & Vallar, G. (2008) The representational space of magnitude: Illusions of length. *Quarterly Journal of Experimental Psychology* 61:1496–514. [JEO]

de Hevia, M. D., Izard, V., Coubart, A., Spelke, E. S. & Streri, A. (2014) Representations of space, time, and number in neonates. *Proceedings of the National Academy of Sciences of the United States of America* 111(13):4809–13. [MDdH]

de Hevia, M. D. & Spelke, E. S. (2010) Number-space mapping in human infants. *Psychological Science* 21:653–60. [JEO]

Deaner, R. O., Isler, K., Burkart, J. & Van Schaik, C. (2007) Overall brain size, and not encephalization quotient, best predicts cognitive ability across non-human primates. *Brain, Behavior and Evolution* 70(2):115–24. doi: 10.1159/000102973. [rTL]

DeCasper, A. J. & Fifer, W. P. (1980) Of human bonding: Newborns prefer their mothers' voices. *Science* 208:1174–76. [MEL]

Defever, E., Reynvoet, B. & Gebuis, T. (2013) Task and age dependent effects of visual stimulus properties on children's explicit numerosity judgments. *Journal of Experimental Child Psychology* 116:216–33. [DS]

Dehaene, S. (1997) *The number sense: How the mind creates mathematics*. Oxford University Press. [aTL, NCJ, EM]

Dehaene, S. (2001) Précis of the number sense. *Mind and Language* 16:16–36. [DS]

Dehaene, S. (2003) The neural basis of the Weber–Fechner law: A logarithmic mental number line. *Trends in Cognitive Sciences* 7(4):145–47. [TG]

Dehaene, S., Bossini, S. & Giraux, P. (1993) The mental representation of parity and number magnitude. *Journal of Experimental Psychology* 122:371–96. [DCB]

Dehaene, S. & Changeux, J. P. (1993) Development of elementary numerical abilities: A neuronal model. *Journal of Cognitive Neuroscience* 5:390–407. doi: 10.1162/jocn.1993.5.4.390. [aTL, IPS]

DeWind, N. K., Adams, G. K., Platt, M. L. & Brannon, E. M. (2015) Modeling the approximate number system to quantify the contribution of visual stimulus features. *Cognition* 142:247–65. doi: 10.1016/j.cognition.2015.05.016. [aTL, JP]

DeWind, N. K. & Brannon, E. M. (2012) Malleability of the approximate number system: Effects of feedback and training. *Frontiers in Human Neuroscience* 6:68. [SFL]

DeWolf, M., Grounds, M. A., Bassok, M. & Holyoak, K. J. (2014) Magnitude comparison with different types of rational numbers. *Journal of Experimental Psychology: Human Perception and Performance* 40(1):71–82. doi: 10.1037/a0032916. [PGS]

Diamond, A. (2013) Executive functions. *Annual Review of Psychology* 64:135–68. doi: 10.1146/annurev-psych-113011-143750. [rTL]

Diester, I. & Nieder, A. (2007) Semantic associations between signs and numerical categories in the prefrontal cortex. *PLoS Biology* 5(11):e294. [AN]

Ditz, H. M. & Nieder, A. (2015) Neurons selective to the number of visual items in the corvid songbird endbrain. *Proceedings of the National Academy of Sciences of the United States of America* 112(25):7827–32. doi: 10.1073/pnas.1504245112. [aTL]

Dobson, V. & Teller, D. Y. (1978) Visual acuity in human infants: A review and comparison of behavioral and electrophysiological studies. *Vision Research* 18(11):1469–83. doi: 10.1016/0042-6989(78)90001-9. [aTL]

Dormal, V., Andres, M. & Pesenti, M. (2012) Contribution of the right intraparietal sulcus to numerosity and length processing: An fMRI-guided TMS study. *Cortex* 48(5):623–29. doi: 10.1016/j.cortex.2011.05.019. [aTL]

Downing, P. E., Jiang, Y., Shuman, M. & Kanwisher, N. (2001) A cortical area selective for visual processing of the human body. *Science* 293(5539):2470–73. [NG]

Dundas, E., Plaut, D. & Behrmann, M. (2013) The joint development of hemispheric lateralization for words and faces. *Journal of Experimental Psychology: General* 142(2):348–58. doi: 10.1037/a0029503. [NG]

Dundas, E., Plaut, D. C. & Behrmann, M. (2014) An ERP investigation of the codevelopment of hemispheric lateralization of face and word recognition. *Neuropsychologia* 61:315–23. [NG]

Durgin, F. H. (1995) Texture density adaptation and the perceived numerosity and distribution of texture. *Journal of Experimental Psychology: Human Perception and Performance* 21(1):149–69. doi: 10.1037/0096-1523.21.1.149. [FHD, IPS, rTL]

Durgin, F. H. (2008) Texture density adaptation and visual number revisited. *Current Biology* 18(18):R855–56. doi: 10.1016/j.cub.2008.07.053. [aTL]

Durgin, F. H. (2016) Magnitudes in the coding of visual multitudes: Evidence from adaptation. In: *Continuous issues in numerical cognition: How many or how much?* ed. A. Henik, pp. 245–70. Elsevier. [FHD]

Eger, E., Michel, V., Thirion, B., Amadon, A., Dehaene, S. & Kleinschmidt, A. (2009) Deciphering cortical number coding from human brain activity patterns. *Current Biology* 19(19):1608–15. [MDdH]

Eger, E., Pinel, P., Dehaene, S. & Kleinschmidt, A. (2015) Spatially invariant coding of numerical information in functionally defined subregions of human parietal cortex. *Cerebral Cortex* 25(5):1319–29. Available at: http://cercor.oxfordjournals.org/content/25/5/1319.short. [aTL]

Eimas, P. D. (1975) Auditory and phonetic coding of the cues for speech: Discrimination of the [rl] distinction by young infants. *Perception & Psychophysics* 18(5):341–47. [OR]

Eimas, P. D., Siqueland, E. R., Jusczyk, P. & Vigorito, J. (1971) Speech perception in infants. *Science* 171(3968):303–306. [OR]

Eiselt, A. K. & Nieder, A. (2016) Single-cell coding of sensory, spatial and numerical magnitudes in primate prefrontal, premotor and cingulate motor cortices. *Experimental Brain Research* 234:241–54. [AN]

Epstein, R. & Kanwisher, N. (1998) A cortical representation of the local visual environment. *Nature* 392(6676):598–601. [NG]

Espy, K. A., McDiarmid, M. M., Cwik, M. F., Stalets, M. M., Hamby, A. & Senn, T. E. (2004) The contribution of executive functions to emergent mathematic skills in preschool children. *Developmental Neuropsychology* 26(1):465–86. doi: 10.1207/s15326942dn2601_6. [aTL]

Euclid (300 BC/1956) *The elements*, trans. T. L. Heath. Dover. [FHD]

Fantz, R. L., Ordy, J. M. & Udelf. M. S. (1962) Maturation of pattern vision in infants during the first six months. *Journal of Comparative and Physiological Psychology* 55:907–17. doi: 10.1037/h0044173. [DCH]

Farroni, T., Valenza, E., Simion, F. & Umiltà, C. (2000) Configural processing at birth: Evidence for perceptual organisation. *Perception* 29(3):355–72. [MDdH]

Fazio, L. K., Bailey, D. H., Thompson, C. A. & Siegler, R. S. (2014) Relations of different types of numerical magnitude representations to each other and to mathematics achievement. *Journal of Experimental Child Psychology* 123:53–72. Available at: http://www.sciencedirect.com/science/article/pii/S0022096514000204. [aTL, MI]

Feigenson, L. (2011) Predicting sights from sounds: 6-month-olds' intermodal numerical abilities. *Journal of Experimental Child Psychology* 110(3):347–61. doi: 10.1016/j.jecp.2011.04.004. [DCH, MEL, rTL]

Feigenson, L. & Carey, S. (2003) Tracking individuals via object-files: Evidence from infants' manual search. *Developmental Science* 6(5):568–84. doi: 10.1111/1467-7687.00313. [aTL]

Feigenson, L., Carey, S. & Spelke, E. (2002) Infants' discrimination of number versus continuous extent. *Cognitive Psychology* 44:33–66. [RR]

Feigenson, L., Dehaene, S. & Spelke, E. (2004) Core systems of number. *Trends in Cognitive Sciences* 8(7):307–14. doi: 10.1016/j.tics.2004.05.002. [aTL, RM, RR]

Féron, J., Gentaz, E. & Streri, A. (2006) Evidence of amodal representation of small numbers across visuo-tactile modalities in 5-month-old infants. *Cognitive Development* 21(2):81–92. doi: 10.1016/j.cogdev.2006.01.005. [rTL]

Fiez, J. A. & Petersen, S. E. (1998) Neuroimaging studies of word reading. *Proceedings of the National Academy of Sciences of the United States of America* 95(3):914–21. [NG]

Fornaciai, M. & Park, J. (2017) Distinct neural signatures for very small and very large numerosities. *Frontiers in Human Neuroscience* 11:21. doi: 10.3389/fnhum.2017.00021. [JP]

Franconeri, S. L., Bemis, D. K. & Alvarez, G. A. (2009) Number estimation relies on a set of segmented objects. *Cognition* 113(1):1–13. doi: 10.1016/j.cognition.2009.07.002. [AC]

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Frederick, S., Loewenstein, G. & O'Donoghue, T. (2002) Time discounting and time preference: A critical review. *Journal of Economic Literature* 40(2):351–401. [CYO]

Frith, C. D. & Frith, U. (1972) The solitaire illusion: An illusion of numerosity. *Perception & Psychophysics* 11:409–10. [JEO, IPS]

Frost, R., Siegelman, N., Narkiss, A. & Afek, L. (2013) What predicts successful literacy acquisition in a second language? *Psychological Science* 24(7):1243–52. doi: 10.1177/0956797612472207. [aTL]

Frye, D., Baroody, A. J., Burchinal, M., Carver, S. M., Jordan, N. C. & McDowell, J. (2013) *Teaching math to young children: A practice guide (NCEE 2014-4005).* U.S. Department of Education, Institute of Education Sciences, National Center for Education Evaluation and Regional Assistance. Available at: http://ies.ed.gov/ncee/wwc/ pdf/practice_guides/early_math_pg_111313.pdf. [NCJ]

Fuhs, M. W. & McNeil, N. M. (2013) ANS acuity and mathematics ability in preschoolers from low-income homes: Contributions of inhibitory control. *Developmental Science* 16:136–48. [MI]

Gabay, S., Kalanthroff, E., Henik, A. & Gronau, N. (2016) Conceptual size representation in ventral visual cortex. *Neuropsychologia* 81:198–206. [NG]

Gabay, S., Leibovich, T., Henik, A. & Gronau, N. (2013) Size before numbers: Conceptual size primes numerical value. *Cognition* 129(1):18–23. [NG]

Gallistel, C. R. (2011) Mental magnitudes. In: *Space, time and number in the brain: Searching for the foundations of mathematical thought*, ed. S. Dehaene & L. Brannon, pp. 3–12. Elsevier. [RR]

Gallistel, C. R. & Gelman, R. (2000) Non-verbal numerical cognition: From reals to integers. *Trends in Cognitive Sciences* 4(2):59–65. doi: 10.1016/S1364-6613(99)01424-2. [PGS]

Gao, F., Levine, S. C. & Huttenlocher, J. (2000) What do infants know about continuous quantity? *Journal of Experimental Child Psychology* 77(1):20–29. [KSM]

Gathers, A. D., Bhatt, R. S., Corbly, C., Farley, A. & Joseph, J. E. (2004) Developmental shifts in cortical loci for face and object recognition. *NeuroReport* 15:1549–53. doi: 10.1097/01.wnr.0000133299.84901.86. [NG]

Gebuis, T., Cohen Kadosh, R. & Gevers, W. (2016) Sensory-integration system rather than approximate number system underlies numerosity processing: A critical review. *Acta Psychologica* 171:17–35. [MI, DS]

Gebuis, T., Gevers, W. & Cohen Kadosh, R. (2014) Topographic representation of high-level cognition: Numerosity or sensory processing? *Trends in Cognitive Sciences* 18(1):1–3. doi: 10.1016/j.tics.2013.10.002. [aTL, JEO]

Gebuis, T. & Reynvoet, B. (2011) Generating nonsymbolic number stimuli. *Behavior Research Methods* 43(4):981–86. doi: 10.3758/s13428-011-0097-5. [aTL]

Gebuis, T. & Reynvoet, B. (2012a) Continuous visual properties explain neural responses to nonsymbolic number. *Psychophysiology* 49(11):1481–91. doi: 10.1111/j.1469-8986.2012.01461.x. [aTL]

Gebuis, T. & Reynvoet, B. (2012b) The interplay between nonsymbolic number and its continuous visual properties. *Journal of Experimental Psychology: General* 141(4):642–48. doi: 10.1037/a0026218. [aTL, TG, JP, DS, IPS]

Gebuis, T. & Reynvoet, B. (2012c) The role of visual information in numerosity estimation. *PLoS ONE* 7(5):e37426. doi: 10.1371/journal.pone.0037426. [aTL, AC, DCB, TG]

Gebuis, T. & Reynvoet, B. (2013) The neural mechanisms underlying passive and active processing of numerosity. *NeuroImage* 70:301–307. doi: 10.1016/j.neuroimage.2012.12.048. [aTL, JP]

Gebuis, T. & Reynvoet, B. (2014) The neural mechanism underlying ordinal numerosity processing. *Journal of Cognitive Neuroscience* 26:1013–20. doi: 10.1162/jocn_a_00541. [aTL, DCH]

Gebuis, T. & van der Smagt, M. J. (2011) False approximations of the approximate number system? *PLoS ONE* 6(10):e25405. doi: 10.1371/journal.pone.0025405. [rTL]

Gegenfurtner, K. R. & Hawken, M. J. (1996) Perceived velocity of luminance, chromatic and non-Fourier stimuli: Influence of contrast and temporal frequency. *Vision Research* 36(9):1281–90. [DCB]

Germine, L. T., Duchaine, B. & Nakayama, K. (2011) Where cognitive development and aging meet: Face learning ability peaks after age 30. *Cognition* 118:201–10. doi: 10.1016/j.cognition.2010.11.002. [NG]

Gevers, W., Cohen Kadosh, R. & Gebuis, T. (2016) The sensory integration theory: An alternative to the approximate number system. In: *Continuous issues in numerical cognition*, ed. A. Henik, pp. 405–18. Elsevier. doi: 10.1016/B978-0-12-801637-4.00018-4. [aTL, TG]

Gilmore, C., Attridge, N., Clayton, S., Cragg, L., Johnson, S., Marlow, N., Simms, V. & Inglis, M. (2013) Individual differences in inhibitory control, not non-verbal number acuity, correlate with mathematics achievement. *PLoS ONE* 8:e67374. doi: 10.1371/journal.pone.0067374. [MI]

Gilmore, C., Cragg, L., Hogan, G. & Inglis, M. (2016) Congruency effects in dot comparison tasks: Convex hull is more important than dot area. *Journal of Cognitive Psychology* 28(8):923–31. doi: 10.1080/20445911.2016.1221828. [rTL]

Ginsburg, N. & Nicholls, A. (1988) Perceived numerosity as a function of item size. *Perceptual and Motor Skills* 67(2):656–58. doi: 10.2466/pms.1988.67.2.656. [JP, rTL]

Girelli, L., Lucangeli, D. & Butterworth, B. (2000) The development of automaticity in accessing number magnitude. *Journal of Experimental Child Psychology* 76:104–22. [OR]

Gliksman, Y., Naparstek, S., Ifergane, G. & Henik, A. (2015) The role of the left intraparietal sulcus (IPS) in visual and imagery comparisons: Evidence from acquired acalculia. Manuscript submitted for publication. [aTL]

Gomez, A., Piazza, M., Jobert, A., Dehaene-Lambertz, G., Dehaene, S. & Huron, C. (2015) Mathematical difficulties in developmental coordination disorder: Symbolic and nonsymbolic number processing. *Research in Developmental Disabilities* 43–44:167–78. Available at: http://www.sciencedirect.com/science/article/pii/S0891422215000682. [aTL]

Gordon, P. (2004) Numerical cognition without words: Evidence from Amazonia. *Science* 306:496–99. [FHD]

Goren, C. C., Sarty, M. & Wu, P. Y. (1975) Visual following and pattern discrimination of face-like stimuli by newborn infants. *Pediatrics* 56(4):544–49. [NG]

Graziano, M. S. A. (2000) Coding the location of the arm by sight. *Science* 290 (5497):1782–86. doi: 10.1126/science.290.5497.1782. [TL]

Greene, J. D., Nystrom, L. E., Engell, A. D., Darley, J. M. & Cohen, J. D. (2004) The neural bases of cognitive conflict and control in moral judgment. *Neuron* 44 (2):389–400. doi: 10.1016/j.neuron.2004.09.027. [aTL]

Grill-Spector, K. & Weiner, K. S. (2014) The functional architecture of the ventral temporal cortex and its role in categorization. *Nature Reviews Neuroscience* 15 (8):536–48. [NG]

Gross, H. J., Pahl, M., Si, A., Zhu, H., Tautz, J. & Zhang, S. (2009) Number-based visual generalisation in the honeybee. *PLoS ONE* 4(1):e4263. doi: 10.1371/journal.pone.0004263. [aTL]

Guellai, B. & Streri, A. (2011) Cues for early social skills: Direct gaze modulates newborns' recognition of talking faces. *PLoS ONE* 6(4):e18610. [MDdH]

Halberda, J. & Feigenson, L. (2008) Developmental change in the acuity of the "number sense": The approximate number system in 3-, 4-, 5-, and 6-year-olds and adults. *Developmental Psychology* 44(5):1457–65. doi: 10.1037/a0012682. [PGS]

Halberda, J., Ly, R., Wilmer, J. B., Naiman, D. Q. & Germine, L. (2012) Number sense across the lifespan as revealed by a massive Internet-based sample. *Proceedings of the National Academy of Sciences of the United States of America* 109(28):11116–20. doi: 10.1073/pnas.1200196109. [IPS]

Halberda, J., Mazzocco, M. M. & Feigenson, L. (2008) Individual differences in non-verbal number acuity correlate with maths achievement. *Nature* 455 (7213):665–68. doi: 10.1038/nature07246. [aTL, DCB, DS]

Hansen, N., Jordan, N. C., Fernandez, E., Siegler, R. S., Fuchs, L. S., Gersten, R. & Micklos, D. A. (2015) General and math-specific predictors of sixth-graders' knowledge of fractions. *Cognitive Development* 35:34–49. doi: 10.1016/j.cogdev.2015.02.001. [NCJ]

Harvey, B. M., Fracasso, A., Petridou, N. & Dumoulin, S. O. (2015) Topographic representations of object size and relationships with numerosity reveal generalized quantity processing in human parietal cortex. *Proceedings of the National Academy of Sciences of the United States of America* 112(44):13525–30. doi: 10.1073/pnas.1515414112. [DCB, MDdH, SFL]

Harvey, B. M., Klein, B. P., Petridou, N. & Dumoulin, S. O. (2013) Topographic representation of numerosity in the human parietal cortex. *Science* 341 (6150):1123–26. doi: 10.1126/science.1239052. [aTL, DCB, MDdH]

Hassinger-Das, B., Jordan, N. C., Glutting, J., Irwin, C. & Dyson, N. (2014) Domain general mediators of the relation between kindergarten number sense and first-grade mathematics achievement. *Journal of Experimental Child Psychology* 118:78–92. doi: 10.1016/jcep.2013.09.008. [NCJ]

Hasson, U., Levy, I., Behrmann, M., Hendler, T. & Malach, R. (2002) Eccentricity bias as an organizing principle for human high order object areas. *Neuron* 34:479–90. [NG]

He, L., Zhang, J., Zhou, T. & Chen, L. (2009) Connectedness affects dot numerosity judgment: Implications for configural processing. *Psychonomic Bulletin and Review* 16(3):509–17. doi: 10.3758/PBR.16.3.509. [AC]

Held, R. & Hein, A. (1963) Movement-produced stimulation in the development of visually guided behavior. *Journal of Comparative and Physiological Psychology* 56(5):872–76. [OR]

Henik, A., Gliksman, Y., Kallai, A & Leibovich, T. (2017) Size perception and the foundation of Numerical Processing. *Current Directions in Psychological Science* 26(1):48–51. [aTL]

Henik, A., Leibovich, T., Naparstek, S., Diesendruck, L. & Rubinsten, O. (2012) Quantities, amounts, and the numerical core system. *Frontiers in Human Neuroscience* 5:186. doi: 10.3389/fnhum.2011.00186. [aTL]

Henik, A. & Tzelgov, J. (1982) Is three greater than five: The relation between physical and semantic size in comparison tasks. *Memory & Cognition* 10 (4):389–95. doi: 10.3758/BF03202431. [PGS]

Hepper, P. G. & Shahidullah, B. S. (1994) Development of fetal hearing. *Archives of Disease in Childhood* 71:F81–87. [MEL]

Holloway, I. D., Price, G. R. & Ansari, D. (2010) Common and segregated neural pathways for the processing of symbolic and nonsymbolic numerical magnitude: An fMRI study. *NeuroImage* 49(1):1006–17. doi: 10.1016/j.neuroimage.2009.07.071. [aTL]

Downloaded from https://www.cambridge.org/core. IP address: 91.46.197.125, on 07 Sep 2017 at 08:17:55, subject to the Cambridge Core terms of use, available at https://www.cambridge.org/core/terms. https://doi.org/10.1017/S0140525X16002090

Holmes, K. J. & Lourenco, S. F. (2011) Common spatial organization of number and emotional expression: A mental magnitude line. *Brain and Cognition* 77:315–23. [SFL]

Hubbard, E. M., Piazza, M., Pinel, P. & Dehaene, S. (2005) Interactions between number and space in parietal cortex. *Nature Reviews Neuroscience* 6(6):435–48. doi: 10.1038/nrn1684. [DCB]

Hubel, D. H. & Wiesel, T. N. (1977) Ferrier lecture. Functional architecture of macaque monkey visual cortex. *Proceedings of the Royal Society of London, Series B* 198:1–59. [NG]

Huk, A. C. & Durgin, F. H. (1996) Concordance of numerosity comparison and numerosity estimation: Evidence from adaptation [abstract]. *Investigative Ophthalmology & Visual Science* 37:1341. [FHD]

Hume, D. (1748/2007) *An enquiry concerning human understanding*, ed. P. Millican. Oxford University Press. (Original work published in 1748.) [DCH]

Hurewitz, F., Gelman, R. & Schnitzer, B. (2006) Sometimes area counts more than number. *Proceedings of the National Academy of Sciences of the United States of America* 103(51):19599–604. doi: 10.1073/pnas.0609485103. [aTL, AC, DO, KvM]

Huth, A. G., Nishimoto, S., Vu, A. T. & Gallant, J. L. (2012) A continuous semantic space describes the representation of thousands of object and action categories across the human brain. *Neuron* 76(6):1210–24. [NG]

Hyde, D. C., Khanum, S. & Spelke, E. S. (2014) Brief non-symbolic, approximate number practice enhances subsequent exact symbolic arithmetic in children. *Cognition* 131:92–107. [MI]

Im, H. Y., Zhong, S.-H. & Halberda, J. (2016) Grouping by proximity and the visual impression of approximate number in random dot arrays. *Vision Research* 126:291–307. Available at: http://www.sciencedirect.com/science/article/pii/S0042698915002813. [aTL]

Izard, V. & Dehaene, S. (2008) Calibrating the mental number line. *Cognition* 106(3):1221–47. doi: 10.1016/j.cognition.2007.06.004. [TG]

Izard, V., Dehaene-Lambertz, G. & Dehaene, S. (2008) Distinct cerebral pathways for object identity and number in human infants. *PLoS Biology* 6(2):e11. [MDdH]

Izard, V., Sann, C., Spelke, E. S. & Steri, A. (2009) Newborn infants perceive abstract numbers. *Proceedings of the National Academy of Sciences of the United States of America* 106(25):10382–85. [arTL, DCB, MDdH, MEL, DCH, EM, SFL, KvM]

Jacob, S. N. & Nieder, A. (2009) Tuning to non-symbolic proportions in the human frontoparietal cortex. *European Journal of Neuroscience* 30(7):1432–42. doi: 10.1111/j.1460-9568.2009.06932.x. [PGS]

Jacob, S. N., Vallentin, D. & Nieder, A. (2012) Relating magnitudes: The brain's code for proportions. *Trends in Cognitive Sciences* 16(3):157–66. doi: 10.1016/j.tics.2012.02.002. [PGS]

Jancke, L. (2001) The role of the inferior parietal cortex in linking the tactile perception and manual construction of object shapes. *Cerebral Cortex* 11(2):114–21. doi: 10.1093/cercor/11.2.114. [aTL]

Jarjoura, W. & Karni, A. (2016) A novel tactile Braille–Stroop test (TBSt). *British Journal of Visual Impairment* 34(1):72–82. [OR]

Johnson, M. H. (2011) Interactive specialization: A domain-general framework for human functional brain development? *Developmental Cognitive Neuroscience* 1(1):7–21. [RM]

Johnson, M. H., Dziurawiec, S., Ellis, H. & Morton, J. (1991) Newborns' preferential tracking of face-like stimuli and its subsequent decline. *Cognition* 40(1):1–19. [NG]

Johnson, S. P. & Aslin, R. N. (1995) Perception of object unity in 2-month-old infants. *Developmental Psychology* 31:739–45. [SFL]

Jordan, K. E. & Baker, J. (2011) Multisensory information boosts numerical matching abilities in young children. *Developmental Science* 14(2):205–13. doi: 10.1111/j.1467-7687.2010.00966.x. [aTL]

Jordan, K. E. & Brannon, E. M. (2006) The multisensory representation of number in infancy. *Proceedings of the National Academy of Sciences of the United States of America* 103(9):3486–89. doi: 10.1073/pnas.0508107103. [DCH, rTL]

Jordan, N. C. & Dyson, N. (2016) Catching math problems early: Findings from the number sense intervention project. In *Continuous issues in numerical cognition: How many or how much?* ed. A. Henik, pp. 60–81. Elsevier. [NCJ]

Jordan, N. C., Hansen, N., Fuchs, L. S., Siegler, R. S., Gersten, R. & Micklos, D. (2013) Developmental predictors of fraction concepts and procedures. *Journal of Experimental Child Psychology* 116:45–58. doi: 10.1016/j.jecp.2013.02.001. [NCJ]

Jordan, K. E., Maclean, E. L. & Brannon, E. M. (2008a) Monkeys match and tally quantities across senses. *Cognition* 108:617–25. [AN]

Jordan, K. E., Suanda, S. H. & Brannon, E. M. (2008b) Intersensory redundancy accelerates preverbal numerical competence. *Cognition* 108(1):210–21. doi: 10.1016/j.cognition.2007.12.001. [aTL, MEL]

Kahneman, D. & Tversky, A. (1979) Prospect theory: An analysis of decision under risk. *Econometrica* 47(2):263–92. [CYO]

Kaminski, J., Call, J. & Fischer, J. (2004) Word learning in a domestic dog: Evidence for “fast mapping.” *Science* 304(5677):1682–83. doi: 10.1126/science.1097859. [rTL]

Kanai, R., Paffen, C. L., Hogendoorn, H. & Verstraten, F. A. (2006) Time dilation in dynamic visual display. *Journal of Vision* 6(12):1421–30. doi: 10.1167/6.12.8. [DCB]

Kaneko, S. & Murakami, I. (2009) Perceived duration of visual motion increases with speed. *Journal of Vision* 9(7):14. doi: 10.1167/9.7.14. [DCB]

Kanwisher, N. (2010) Functional specificity in the human brain: A window into the functional architecture of the mind. *Proceedings of the National Academy of Sciences of the United States of America* 107(25):11163–70. [NG]

Kanwisher, N. G., McDermott, J. & Chun, M. M. (1997) The fusiform face area: A module in human extrastriate cortex specialized for face perception. *Journal of Neuroscience* 17:4302–11. [NG]

Karni, A. (1996) The acquisition of perceptual and motor skills: A memory system in the adult human cortex. *Cognitive Brain Research* 5(1):39–48. [OR]

Karni, A. & Bertini, G. (1997) Learning perceptual skills: Behavioral probes into adult cortical plasticity. *Current Opinion in Neurobiology* 7(4):530–35. [OR]

Katzin, N., Katzin, D., Salti, M. & Henik, A. (2016) Convex hull as a heuristic. Poster presented at the Psychonomics Society 57th Annual Meeting, Boston, MA. [rTL]

Kaufman, E. L., Lord, M. W., Reese, T. W. & Volkmann, J. (1949) The discrimination of visual number. *American Journal of Psychology* 62:498–525. [aTL, FHD, RM]

Kaufmann, L., Koppelstaetter, F., Delazer, M., Siedentopf, C., Rhomberg, P., Golaszewski, S., Felber, S. & Ischebeck, A. (2005) Neural correlates of distance and congruity effects in a numerical Stroop task: An event-related fMRI study. *NeuroImage* 25(3):888–98. doi: 10.1016/j.neuroimage.2004.12.041. [aTL]

Keller, L. & Libertus, M. (2015) Inhibitory control may not explain the link between approximation and math abilities in kindergarteners from middle class families. *Frontiers in Psychology* 6:685. doi: 10.3389/fpsyg.2015.00685. [aTL]

Kellman, P. J. & Arterberry, M. E. (2007) Infant visual perception. In: *Handbook of child psychology. Vol. 2. Cognition, perception, and language*, ed. R. Siegler and D. Kuhn, pp. 109–60. Wiley. [DCH]

Kellman, P. J. & Spelke, E. S. (1983) Perception of partly occluded objects in infancy. *Cognitive Psychology* 15:483–524. [SFL]

Kestenbaum, R., Termine, N. & Spelke, E. S. (1987) Perception of objects and object boundaries by 3-month-old infants. *British Journal of Developmental Psychology* 5:367–83. [SFL]

Khanum, S., Hanif, R., Spelke, E., Berteletti, I. & Hyde, D. C. (2016) Effects of non-symbolic approximate number practice on symbolic numerical abilities in Pakistani children. *PLoS ONE* 11:e0164436. [MI]

Kim, B. K. & Zauberman, G. (2009) Perception of anticipatory time in temporal discounting. *Journal of Neuroscience, Psychology, and Economics* 2(2):91–101. [CYO]

Kirjakovski, A. & Matsumoto, E. (2016) Numerosity underestimation in sets with illusory contours. *Vision Research* 122:34–42. doi: 10.1016/j.visres.2016.03.005. [AC]

Kobayashi, T., Hiraki, K. & Hasegawa, T. (2005) Auditory–visual intermodal matching of small numerosities in 6-month-old infants. *Developmental Science* 8(5):409–19. doi: 10.1111/j.1467-7687.2005.00429.x. [rTL]

Kobayashi, T., Hiraki, K., Mugitani, R. & Hasegawa, T. (2004) Baby arithmetic: One object plus one tone. *Cognition* 91(2):B23–34. doi: 10.1016/j.cognition.2003.09.004. [rTL]

Konkle, T. & Oliva, A. (2012) A real-world size organization of object responses in occipitotemporal cortex. *Neuron* 74(6):1114–24. doi: 10.1016/j.neuron.2012.04.036. [NG, rTL]

Kornienko, T. (2013) Nature's measuring tape: A cognitive basis for adaptive utility. Working paper, University of Edinburgh. [CYO]

Kourtzi, Z. & Grill-Spector, K. (2005) fMRI adaptation: A tool for studying visual representations in the primate brain. In: *Fitting the mind into the world: Adaptation and after-effects in high level vision*, ed. G. Rhodes and C. Clifford, pp. 173–88. Oxford University Press. [DCH]

Krajcsi, A., Lengyel, G. & Kojouharova, P. (2016) The source of the symbolic numerical distance and size effects. *Frontiers in Psychology* 7:1795. doi: 10.3389/fpsyg.2016.01795. [DS]

Kriegeskorte, N., Mur, M., Ruff, D. A., Kiani, R., Bodurka, J., Esteky, H., Tanaka, K. & Bandettini, P. A. (2008) Matching categorical object representations in inferior temporal cortex of man and monkey. *Neuron* 60:1126–41. [NG]

Krueger, L. E. (1972) Perceived numerosity. *Perception & Psychophysics* 11:5–9. [FHD]

Krueger, L. E. (1982) Single judgments of numerosity. *Perception & Psychophysics* 31(2):175–82. [TG]

Kuhl, P. K. (2010) Brain mechanisms in early language acquisition. *Neuron* 67(5):713–27. [OR]

Landerl, K., Bevan, A. & Butterworth, B. (2004) Developmental dyscalculia and basic numerical capacities: A study of 8–9–year-old students. *Cognition* 93:99–125. doi: 10.1016/j.cognition.2003.11.004. [NCJ]

Lasky, R. E., Syrdal-Lasky, A. & Klein, R. E. (1975) VOT discrimination by four to six and a half month old infants from Spanish environments. *Journal of Experimental Child Psychology* 20(2):215–25. [OR]

Downloaded from https://www.cambridge.org/core. IP address: 91.46.197.129, on 07 Sep 2017 at 08:17:55, subject to the Cambridge Core terms of use, available at https://www.cambridge.org/core/terms. https://doi.org/10.1017/S0140525X16002090

Leibovich, T. & Ansari, D. (2016) The symbol-grounding problem in numerical cognition: A review of theory, evidence and outstanding questions. *Canadian Journal of Experimental Psychology* 70(1):12–23. [arTL]

Leibovich, T. & Henik, A. (2013) Magnitude processing in non-symbolic stimuli. *Frontiers in Psychology* 4:375. doi: 10.3389/fpsyg.2013.00375. [aTL, MJB]

Leibovich, T. & Henik, A. (2014) Comparing performance in discrete and continuous comparison tasks. *Quarterly Journal of Experimental Psychology* 67(5):1–19. doi: 10.1080/17470218.2013.837940. [arTL, DCH]

Leibovich, T., Henik, A. & Salti, M. (2015) Numerosity processing is context driven even in the subitizing range: An fMRI study. *Neuropsychologia* 77:137–47. doi: 10.1016/j.neuropsychologia.2015.08.016. [arTL, AC, DCH]

Leibovich, T., Kallai, A. & Itamar, S. (2016a) What do we measure when we measure magnitudes? In: *Continuous issues in numerical cognition*, ed. A. Henik, pp. 355–73. Elsevier. doi: 10.1016/B978-0-12-801637-4.00016-0. [arTL, PGS]

Leibovich, T., Vogel, S. E., Henik, A. & Ansari, D. (2016b) Asymmetric processing of numerical and non-numerical magnitudes in the brain: An fMRI study. *Journal of Cognitive Neuroscience* 28(1):166–76. doi: 10.1162/jocn_a_00887. [aTL, JP]

Leroux, G., Spiess, J., Zago, L., Rossi, S., Lubin, A., Turbelin, M.-R., Mazoyer, B., Tzourio-Mazoyer, N., Houdé, O. & Joliot, M. (2009) Adult brains don't fully overcome biases that lead to incorrect performance during cognitive development: An fMRI study in young adults completing a Piaget-like task. *Developmental Science* 12(2):326–38. doi: 10.1111/j.1467-7687.2008.00785.x. [aTL, NG]

Leslie, A. M., Xu, F., Tremoulet, P. D., & Scholl, B. J. (1998) Indexing and the object concept: Developing 'what' and 'where' systems. *Trends in Cognitive Sciences* 2:10–18. [SFL]

Lettvin, J., Maturana, H., McCulloch, W. & Pitts, W. (1959) What the frog's eye tells the frog's brain. *Proceedings of the IRE* 47(11):1940–51. doi: 10.1109/JRPROC.1959.287207. [aTL]

LeVay, S., Wiesel, T. N. & Hubel, D. H. (1980) The development of ocular dominance columns in normal and visually deprived monkeys. *Journal of Comparative Neurology* 191:1–51. [CA]

Levy, I., Hasson, U., Avidan, G., Hendler, T. & Malach, R. (2001) Center-periphery organization of human object areas. *Nature Neuroscience* 4:533–39. [NG]

Libertus, M. E., Starr, A. & Brannon, E. M. (2014) Number trumps area for 7-month-old infants. *Developmental Psychology* 50(1):108–12. doi: 10.1037/a0032986. [aTL, MDdH, MEL, SS]

Lindskog, M. & Winman, A. (2016) No evidence of learning in non-symbolic numerical tasks – A comment on Park & Brannon (2014) *Cognition* 150:243–47. [MI]

Lipton, J. S. & Spelke, E. S. (2003) Origins of number sense large-number discrimination in human infants. *Psychological Science* 14(5):396–401. doi: 10.1111/1467-9280.01453. [MDdH, MEL, SS]

Lipton, J. S. & Spelke, E. S. (2004) Discrimination of large and small numerosities by human infants. *Infancy* 5(3):271–90. doi: 10.1207/s15327078in0503_2. [SS]

Logan, G. D. (1997) The automaticity of academic life: Unconscious applications of an implicit theory. In: *The automaticity of everyday life: Advances in social cognition, vol. 10*, ed. R. S. Wyer, Jr., pp. 157–79. Psychology Press, Taylor and Francis. [OR]

Lourenco, S. F. (2015) On the relation between numerical and non-numerical magnitudes: Evidence for a general magnitude system. In: *Evolutionary origins and early development of number processing*, ed. D. C. Geary, D. B. Berch & K. M. Koepke, pp. 145–74. Elsevier Academic Press. [SFL]

Lourenco, S. F. (2016) How do humans represent numerical and nonnumerical magnitudes? Evidence for an integrated system of magnitude representation across development. In: *Continuous issues in numerical cognition: How many or how much*, ed. A. Henik, pp. 375–403. Elsevier Academic Press. [SFL]

Lourenco, S. F. & Aulet, L. S. (submitted) Cross-magnitude interactions across development: Longitudinal support for a general magnitude system. [SFL]

Lourenco, S. F., Ayzenberg, V. & Lyu, J. (2016) A general magnitude system in human adults: Evidence from a subliminal priming paradigm. *Cortex* 81:93–103. [SFL]

Lourenco, S. F. & Bonny, J. W. (2016) Representations of numerical and non-numerical magnitude both contribute to mathematical competence in children. *Developmental Science*. Available online May 4, 2016. doi: 10.1111/desc.12418. [SFL]

Lourenco, S. F. & Longo, M. R. (2010) General magnitude representation in human infants. *Psychological Science* 21:873–81. [SFL, DO, JEO]

Lucon-Xiccato, T., Dadda, M., Gatto, E. & Bisazza, A. (2017) Development and testing of a rapid method for measuring shoal size discrimination. *Animal Cognition*. 20(2):149–57. doi: 10.1007/s10071-016-1050-x. [CA]

MacAdam, D. L. (1942) Visual sensitivities to color differences in daylight. *Journal of the Optical Society of America* 32(5):247–74. doi:10.1364/JOSA.32.000247. [DCB]

MacLeod, C. M. (1991) Half a century of research on the Stroop effect: An integrative review. *Psychological Bulletin* 109:163–203. [OR]

Maguire, E. A., Frith, C. D., Burgess, N., Donnett, J. G. & O'Keefe, J. (1998) Knowing where things are: Parahippocampal involvement in encoding object locations in virtual large-scale space. *Journal of Cognitive Neuroscience* 10 (1):61–76. [NG]

Mandler, G. & Shebo, B. J. (1982) Subitizing: An analysis of its component processes. *Journal of Experimental Psychology: General* 111(1):1–22. [KSM, rTL]

Margolis, E. & Laurence, S. (2013) In defense of nativism. *Philosophical Studies* 165 (2):693–718. [EM]

Matsuzawa, T. (1985) Use of numbers by a chimpanzee. *Nature* 315:57–59. [MJB]

Matthews, P. G. & Chesney, D. L. (2015) Fractions as percepts? Exploring cross-format distance effects for fractional magnitudes. *Cognitive Psychology* 78:28–56. doi: 10.1016/j.cogpsych.2015.01.006. [PGS]

Matthews, P. G. & Lewis, M. R. (2016) Fractions we cannot ignore: The nonsymbolic ratio congruity effect. *Cognitive Science*. Available online. doi: 10.1111/cogs.12419. [PGS]

Matthews, P. G., Lewis, M. R. & Hubbard E. M. (2016) Individual differences in nonsymbolic ratio processing predict symbolic math performance. *Psychological Science* 27(2):191–202. doi: 10.1177/0956797615617799. [NCJ, PGS]

Mazzocco, M. M. M. & Thompson, R. E. (2005) Kindergarten predictors of math learning disability. *Learning Disabilities Research & Practice* 20(3):142–55. doi: 10.1111/j.1540-5826.2005.00129.x. [NCJ]

McCarthy, G., Puce, A., Gore, J. C. & Allison, T. (1997) Face-specific processing in the human fusiform gyrus. *Journal of Cognitive Neuroscience* 9:605–10. [NG]

McComb, K., Packer, C. & Pusey, A. (1994) Roaring and numerical assessment in contests between groups of female lions, *Panthera leo*. *Animal Behaviour* 47 (2):379–87. doi: 10.1006/anbe.1994.1052. [aTL]

McCrink, K. & Opfer, J. E. (2014) Development of spatial–numerical associations. *Current Directions in Psychological Science* 23:439–45. [JEO]

McCrink, K. & Wynn, K. (2004) Large-number addition and subtraction by 9-month-old infants. *Psychological Science* 15(11):776–81. [KvM]

McCrink, K. & Wynn, K. (2007) Ratio abstraction by 6-month-old infants. *Psychological Science* 18(8):740–45. doi: 10.1111/j.1467-9280.2007.01969.x. [PGS]

McMullen, J., Hannula-Sormunen, M. M. & Lehtinen, E. (2015) Preschool spontaneous focusing on numerosity predicts rational number conceptual knowledge 6 years later. *ZDM Mathematics Education* 47(5):813–24. doi: 10.1007/s11858-015-0669-4. [NCJ]

Meck, W. H. & Church, R. M. (1983) A mode control model of counting and timing processes. *Journal of Experimental Psychology: Animal Behavior Processes* 9:320–34. [aTL, CA]

Merkley, R. & Ansari, D. (2016) Why numerical symbols count in the development of mathematical skills: Evidence from brain and behavior. *Current Opinion in Behavioral Sciences* 10:14–20. [KSM]

Merkley, R., Matejko, A. A. & Ansari, D. (2017) Strong causal claims require strong evidence: A commentary on Wang and colleagues. *Journal of Experimental Child Psychology* 153:163–67. [MI]

Miller, A. L. & Baker, R. A. (1968) The effects of shape, size, heterogeneity, and instructional set on the judgment of visual number. *American Journal of Psychology* 81(1):83–91. [JP]

Mix, K. S., Huttenlocher, J. & Levine, S. C. (2002a) Multiple cues for quantification in infancy: Is number one of them? *Psychological Bulletin* 128(2):278–94. doi: 10.1037/0033-2909.128.2.278. [arTL, TG, KSM, JP]

Mix, K. S., Huttenlocher, J. & Levine, S. C. (2002b) *Quantitative development in infancy and early childhood.* Oxford University Press. [KSM]

Mix, K. S., Levine, S. C. & Huttenlocher, J. (1997) Numerical abstraction in infants: Another look. *Developmental Psychology* 33(3):423–28. doi: 10.1037/0012-1649.33.3.423. [rTL]

Mix, K. S., Levine, S. C. & Newcombe, N. S. (2016) Development of quantitative thinking across correlated dimensions. In: *Continuous issues in numerical cognition*, ed. A. Henik, pp. 1–33. Elsevier. doi: 10.1016/B978-0-12-801637-4.00001-9. [arTL, KSM, RM]

Mix, K. S. & Sandhofer, C. M. (2007) Do we need a number sense? In: Integrating the mind, ed. M. J. Roberts, pp. 293–326. Psychology Press. [aTL]

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A. & Wager, T. D. (2000) The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology* 41(1):49–100. doi: 10.1006/cogp.1999.0734. [aTL]

Moore, D., Benenson, J., Reznick, J. S., Peterson, M. & Kagan, J. (1987) Effect of auditory numerical information on infants' looking behavior: Contradictory evidence. *Developmental Psychology* 23(5):665–70. doi: 10.1037/0012-1649.23.5.665. [rTL]

Morton, J. B. (2010) Understanding genetic, neurophysiological, and experiential influences on the development of executive functioning: The need for developmental models. *Wiley Interdisciplinary Reviews: Cognitive Science* 1(5):709–23. doi: 10.1002/wcs.87. [aTL]

Moyer, R. S. & Landauer, T. K. (1967) Time required for judgements of numerical inequality. *Nature* 215(5109):1519–20. doi: 10.1038/2151519a0. [aTL, PGS]

Mussolin, C., Mejias, S. & Noël, M. P. (2010) Symbolic and nonsymbolic number comparison in children with and without dyscalculia. *Cognition* 115(1):10–25. doi: 10.1016/j.cognition.2009.10.006. [aTL]

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Naghavi, H. R. & Nyberg, L. (2005) Common fronto-parietal activity in attention, memory, and consciousness: Shared demands on integration? Consciousness and Cognition 14(2):390–425. doi: 10.1016/j.concog.2004.10.003. [aTL]

National Research Council (2009) *Mathematics learning in early childhood: Paths toward excellence and equity*, ed. Committee on Early Childhood Mathematics, C.T. Cross, T.A. Woods & H. Schweingruber. Center for Education, Division of Behavioral and Social Sciences and Education. National Academies Press. [NCJ]

Needham, A. (1998) Infants' use of featural information in the segregation of stationary objects. *Infant Behavior and Development* 21:47–76. [SFL]

Negen, J. & Sarnecka, B. W. (2015) Is there really a link between exact-number knowledge and approximate number system acuity in young children? *British Journal of Developmental Psychology* 33(1):92–105. [RM]

Nieder, A. (2005) Counting on neurons: The neurobiology of numerical competence. *Nature Reviews Neuroscience* 6(3):177–90. doi: 10.1038/nrn1626. [aTL]

Nieder, A. (2012) Supramodal numerosity selectivity of neurons in primate prefrontal and posterior parietal cortices. *Proceedings of the National Academy of Sciences of the United States of America* 109:11860–65. [AN]

Nieder, A. (2016) The neuronal code for number. *Nature Reviews Neuroscience* 17:366–82. [AN]

Nieder, A. & Dehaene, S. (2009) Representation of number in the brain. *Annual Review of Neuroscience* 32:185–208. doi: 10.1146/annurev.neuro.051508.135550. [aTL, IPS]

Nieder, A., Diester, I. & Tudusciuc, O. (2006) Temporal and spatial enumeration processes in the primate parietal cortex. *Science* 313:1431–35. [AN]

Nieder, A., Freedman, D. J. & Miller, E. K. (2002) Representation of the quantity of visual items in the primate prefrontal cortex. *Science* 297:1708–11. [AN]

Nys, J. & Content, A. (2012) Judgement of discrete and continuous quantity in adults: Number counts! *Quarterly Journal of Experimental Psychology* 65 (4):675–90. doi: 10.1080/17470218.2011.619661. [aTL, AC, JP]

Odic, D. (2017) Children's intuitive sense of number develops independently of their perception of area, density, length, and time. *Developmental Science*. 2017: e12533. doi: 10.1111/desc.12533 [DO]

Odic, D., Libertus, M. E., Feigenson, L. & Halberda, J. (2013) Developmental change in the acuity of approximate number and area representations. *Developmental Psychology* 49(6):1103–12. [DO, SFL]

Odic, D., Lisboa, J. V., Eisinger, R., Olivera, M. G., Maiche, A. & Halberda, J. (2016) Approximate number and approximate time discrimination each correlate with school math abilities in young children. *Acta Psychologica* 163:17–26. [DO]

O'Hearn, K., Schroer, E., Minshew, N. & Luna, B. (2010) Lack of developmental improvement on a face memory task during adolescence in autism. *Neuropsychologia* 48:3955–60. doi: 10.1016/j.neuropsychologia.2010.08.024. [NG]

Olivola, C. Y. (2015) The cognitive psychology of sensitivity to human fatalities: Implications for life-saving policies. *Policy Insights from the Behavioral and Brain Sciences* 2(1):141–46. [CYO]

Olivola, C. Y. & Chater, N. (2017) Decision by sampling: Connecting preferences to real-world regularities. In: *Big data in cognitive science*, ed. M. N. Jones. pp. 294–319. Psychology Press, Taylor and Francis. [CYO]

Olivola, C. Y., Rheinberger, C. M. & Hammitt, J. K. (2017) Sensitivity to fatalities from frequent small-scale deadly events: A decision by sampling account. Working paper, Carnegie Mellon University. [CYO]

Olivola, C. Y. & Sagara, N. (2009) Distributions of observed death tolls govern sensitivity to human fatalities. *Proceedings of the National Academy of Sciences of the United States of America* 106(52):22151–56. [CYO]

Olivola, C. Y. & Wang, S. W. (2016) Patience auctions: The impact of time vs. money bidding on elicited discount rates. *Experimental Economics* 19(4):864–85. [CYO]

Oppenheimer, D. M., LeBoeuf, R. A. & Brewer, N. T. (2008) Anchors aweigh: A demonstration of cross-modality anchoring and magnitude priming. *Cognition* 106(1):13–26. doi: 10.1016/j.cognition.2006.12.008. [aTL]

Park, J. (2017) A neural basis for the visual sense of number and its development: A steady-state visual evoked potential study in children and adults. *Developmental Cognitive Neuroscience*. Available online March 2, 2017. doi: 10.1016/j.dcn.2017.02.011. [JP]

Park, J., Bermudez, V., Roberts, R. C. & Brannon, E. M. (2016a) Non-symbolic approximate arithmetic training improves math performance in preschoolers. *Journal of Experimental Child Psychology* 152:278–93. [MI]

Park, J. & Brannon, E. M. (2013) Training the approximate number system improves math proficiency. *Psychological Science* 24:2013–19. [MI]

Park, J. & Brannon, E. M. (2014) Improving arithmetic performance with number sense training: An investigation of underlying mechanism. *Cognition* 133:188–200. [MI]

Park, J. & Brannon, E. M. (2016) How to interpret cognitive training studies: A reply to Lindskog & Winman. *Cognition* 150:247–51. [MI]

Park, J., DeWind, N. K., Woldorff, M. G. & Brannon, E. M. (2016b) Rapid and direct encoding of numerosity in the visual stream. *Cerebral Cortex* 26(2): 748–63. doi: 10.1093/cercor/bhv017. [aTL, MDdH, JP]

Pepperberg, I. M. (1994) Numerical competence in an African grey parrot (*Psittacus erithacus*). *Journal of Comparative Psychology* 108:36–44. [MJB]

Piaget, J. (1952) *The child's conception of number*. Psychology Press. [arTL]

Piazza, M. (2010) Neurocognitive start-up tools for symbolic number representations. *Trends in Cognitive Sciences* 14(12):542–51. doi: 10.1016/J.Tics.2010.09.008. [DCB, PGS]

Piazza, M., Facoetti, A., Trussardi, A. N., Berteletti, I., Conte, S., Lucangeli, D., Dehaene, S. & Zorzi, M. (2010) Developmental trajectory of number acuity reveals a severe impairment in developmental dyscalculia. *Cognition* 116 (1):33–41. doi: 10.1016/j.cognition.2010.03.012. [aTL, IPS]

Piazza, M., Izard, V., Pinel, P., Le Bihan, D. & Dehaene, S. (2004) Tuning curves for approximate numerosity in the human intraparietal sulcus. *Neuron* 44 (3):547–55. doi: 10.1016/j.neuron.2004.10.014. [aTL, MDdH, DCH]

Piazza, M., Pica, P., Izard, V., Spelke, E. S. & Dehaene, S. (2013) Education enhances the acuity of the nonverbal approximate number system. *Psychological Science* 24:1037–43. [SFL]

Picon, E. & Odic, D. (in preparation) Visual illusions reveal the primitives of number perception. [DO]

Piffer, L., Miletto Petrazzini, M. E. & Agrillo, C. (2013) Large number discrimination in newborn fish. *PLoS ONE* 8(4):e62466. [CA]

Pinel, P., Piazza, M., Le Bihan, D. & Dehaene, S. (2004) Distributed and overlapping cerebral representations of number, size, and luminance during comparative judgments. *Neuron* 41(6):983–93. doi: 10.1016/S0896-6273(04)00107-2. [aTL, NG, AN]

Pisa, P. E. & Agrillo, C. (2008) Quantity discrimination in felines: A preliminary investigation of the domestic cat (*Felis silvestris catus*). *Journal of Ethology* 27 (2):289–93. doi: 10.1007/s10164-008-0121-0. [aTL]

Poldrack, R. A. & Logan, G. D. (1998) What is the mechanism for fluency in successive recognition? *Acta Psychologica* 98(2):167–81. [OR]

Pollmann, S., Zinke, W., Baumgartner, F., Geringswald, F. & Hanke, M. (2014) The right temporo-parietal junction contributes to visual feature binding. *NeuroImage* 101:289–97. doi: 10.1016/j.neuroimage.2014.07.021. [aTL]

Prelec, D. (1998) The probability weighting function. *Econometrica* 66(3):497–527. [CYO]

Preuss, S. J., Trivedi, C. A., vom Berg-Maurer, C. M., Ryu, S. & Bollmann, J. H. (2014) Classification of object size in retinotectal microcircuits. *Current Biology* 24(20):2376–85. doi: 10.1016/j.cub.2014.09.012. [aTL]

Puce, A., Allison, T., Asgari, M., Gore, J. C. & McCarthy, G. (1996) Differential sensitivity of human visual cortex to faces, letterstrings, and textures: A functional magnetic resonance imaging study. *Journal of Neuroscience* 16:5205–15. Available at: http://www.ncbi.nlm.nih.gov/pubmed/8756449. [NG]

Rakison, D. H. & Poulin-Dubois, D. (2001) Developmental origin of the animate–inanimate distinction. *Psychological Bulletin* 127(2):209–28. [KSM]

Ramirez-Cardenas, A., Moskaleva, M. & Nieder, A. (2016) Neuronal representation of numerosity zero in the primate parieto-frontal number network. *Current Biology* 26:1285–94. [AN]

Read, D. (2004) Intertemporal choice. In: *Blackwell handbook of judgment and decision making*, ed. D. J. Koehler & N. Harvey, pp. 424–43. Blackwell. [CYO]

Resnick, I., Jordan, N. C., Hansen, N., Rajan, V., Rodrigues, J., Siegler, R. S. & Fuchs, L. (2016) Developmental growth trajectories in understanding of fraction magnitude from fourth through sixth grade. *Developmental Psychology* 52 (5):746–57. doi: 10.1037/dev0000102. [NCJ]

Reynvoet, B. & Sasanguie, D. (2016) The symbol grounding problem revisited: A thorough evaluation of the ANS mapping account and the proposal of an alternative account based on symbol–symbol associations. *Frontiers in Psychology* 7:1581. doi: 10.3389/fpsyg.2016.01581. [DS]

Ricciuti, H. N. (1965) Object grouping and selective ordering behavior in infants 12 to 24 months old. *Merrill-Palmer Quarterly of Behavior and Development* 11 (2):129–48. [KSM]

Ridley, R. M. & Baker, H. F. (1982) Stereotypy in monkeys and humans. *Psychological Medicine* 12:61–72. [CA]

Rinne, L., Ye, A. & Jordan, N. C. (2017) Development of fraction comparison strategies: A latent transition analysis. *Developmental Psychology* 53(4):713–30. [NCJ]

Roitman, J. D., Brannon, E. M., & Platt, M. L. (2007) Monotonic coding of numerosity in macaque lateral intraparietal area. *PLoS Biology* 5(8):e208. doi: 10.1371/journal.pbio.0050208. [IPS]

Ross-Sheehy, S., Oakes, L. M. & Luck, S. J. (2003) The development of visual short-term memory capacity in infants. *Child Development* 74(6):1807–22. [KSM]

Rousselle, L. & Noel, M. P. (2007) Basic numerical skills in children with mathematics learning disabilities: A comparison of symbolic vs non-symbolic number magnitude processing. *Cognition* 102:361–95. doi: 10.1016/j.cognition.2006.01.005. [NCJ]

Rubinsten, O. & Henik, A. (2009) Developmental dyscalculia: Heterogeneity might not mean different mechanisms. *Trends in Cognitive Sciences* 13(2):92–99. doi: 10.1016/j.tics.2008.11.002. [aTL]

Rubinsten, O., Henik, A., Berger, A. & Shahar-Shalev, S. (2002) The development of internal representations of magnitude and their association with Arabic numerals. *Journal of Experimental Child Psychology* 81:74–92. [OR]

Rugani, R., Regolin, L. & Vallortigara, G. (2010) Imprinted numbers: Newborn chicks' sensitivity to number vs. continuous extent of objects they have been reared with. *Developmental Science* 13:790–97. [RR]

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Rugani, R., Regolin, L. & Vallortigara, G. (2011) Summation of large numerousness by newborn chicks. *Frontiers in Psychology* 2:179. doi: 10.3389/fpsyg.2011.00179. [RR]

Rugani, R., Vallortigara, G., Priftis, K. & Regolin, L. (2015) Number-space mapping in the newborn chick resembles humans' mental number line. *Science* 347:534–36. [RR]

Rugani, R., Vallortigara, G. & Regolin, L. (2013) Numerical abstraction in young domestic chicks (*Gallus gallus*). *PLoS ONE* 8(6):e65262. doi: 10.1371/journal.pone.0065262. [aTL]

Salti, M., Katzin, N., Katzin, D., Leibovich, T. & Henik, A. (2017) One tamed at a time: A new approach for controlling continuous magnitudes in numerical comparison tasks. *Behavior Research Methods* 49(3):1120–27. doi: 10.3758/s13428-016-0772-7. [arTL]

Sasanguie, D., De Smedt, B., Defever, E. & Reynvoet, B. (2012) Association between basic numerical abilities and mathematics achievement. *British Journal of Developmental Psychology* 30:344–57. [DS]

Sasanguie, D., De Smedt, B. & Reynvoet, B. (2017) Evidence for distinct magnitude systems for symbolic and non-symbolic number. *Psychological Research* 81 (1):231–42. doi: 10.1007/s00426-015-0734-1. [DS]

Scherf, K. S., Behrmann, M., Humphreys, K. & Luna, B. (2007) Visual category-selectivity for faces, places and objects emerges along different developmental trajectories. *Developmental Science* 10:F15–30. doi: 10.1111/j.1467-7687.2007.00595.x. [NG]

Schley, D. R. & Peters, E. (2014) Assessing “economic value”: Symbolic-number mappings predict risky and riskless valuations. *Psychological Science* 25(3):753–61. [CYO]

Schneider, M., Beeres, K., Coban, L., Merz, S., Schmidt, S., Stricker, J. & De Smedt, B. (2017) Associations of non-symbolic and symbolic numerical magnitude processing with mathematical competence: A meta-analysis. *Developmental Science.* 20(30);e12372. doi: 10.1111/desc.12372. [MI]

Shafritz, K. M., Gore, J. C. & Marois, R. (2002) The role of the parietal cortex in visual feature binding. *Proceedings of the National Academy of Sciences of the United States of America* 99(16):10917–22. doi: 10.1073/pnas.152694799. [aTL]

Shakeshaft, N. G. & Plomin, R. (2015) Genetic specificity of face recognition. *Proceedings of the National Academy of Sciences of the United States of America* 112(41):12887–92. doi: 10.1073/pnas.1421881112. [NG]

Shilling, V. M., Chetwynd, A. & Rabbitt, P. M. A. (2002) Individual inconsistency across measures of inhibition: An investigation of the construct validity of inhibition in older adults. *Neuropsychologia* 40(6):605–19. doi: 10.1016/S0028-3932(01)00157-9. [aTL]

Siegler, R. S. (1981) Developmental sequences within and between concepts. *Monographs of the Society for Research in Child Development* 46:1–84. [JEO]

Siegler, R. S. & Booth, J. L. (2005) Development of numerical estimation. In: *Handbook of mathematical cognition*, ed. J. I. D. Campbell, pp. 197–212. Psychology Press, Taylor and Francis. [SS]

Siegler, R. S. & Lortie-Forgues, H. (2014) An integrative theory of numerical development. *Child Development Perspectives* 8(3):144–50. doi: 10.1111/cdep.12077. [NCJ]

Siegler, R. S., Thompson, C. A. & Schneider, M. (2011) An integrated theory of whole number and fractions development. *Cognitive Psychology* 62(4):273–96. Available at: https://doi.org/10.1016/j.cogpsych.2011.03.001. [PGS]

Simonsohn, U., Nelson, L. D. & Simmons, J. P. (2014) *P*-curve: A key to the file-drawer. *Journal of Experimental Psychology: General* 143:534–47. [MI]

Simonsohn, U., Simmons, J. P. & Nelson, L. D. (2015) Better P-curves: Making P-curve analysis more robust to errors, fraud, and ambitious P-hacking, a reply to Ulrich and Miller (2015) *Journal of Experimental Psychology: General* 144:1146–52. [MI]

Slater, A., Morison, V., Somers, M., Mattock, A., Brown, E. & Taylor, D. (1990) Newborn and older infants' perception of partly occluded objects. *Infant Behavior and Development* 13:33–49. [SFL]

Slovic, P. (2007) “If I look at the mass I will never act”: Psychic numbing and genocide. *Judgment and Decision Making* 2(2):79–95. [CYO]

Slusser, E. B. & Sarnecka, B. W. (2011) Find the picture of eight turtles: A link between children's counting and their knowledge of number word semantics. *Journal of Experimental Child Psychology* 110(1):38–51. [RM]

Smets, K., Sasanguie, D., Szücs, D. & Reynvoet, B. (2015) The effect of different methods to construct non-symbolic stimuli in numerosity estimation and comparison. *Journal of Cognitive Psychology* 27(3):310–25. doi: 10.1080/20445911.2014.996568. [aTL, DS]

Smith, L. B., Jones, S. S. & Landau, B. (1996) Naming in young children: A dumb attentional mechanism? *Cognition* 60(2):143–71. [OR]

Sokolowski, H. M., Fias, W., Ononye, C. B. & Ansari, D. (2017) Are numbers grounded in a general magnitude processing system? A functional neuroimaging meta-analysis. *Neuropsychologia*. Available online January 22, 2017. doi: 10.1016/j.neuropsychologia.2017.01.019. [rTL]

Soltész, F. & Szücs, D. (2014) Neural adaptation to non-symbolic number and visual shape: An electrophysiological study. *Biological Psychology* 103:203–11. doi: 10.1016/j.biopsycho.2014.09.006. [aTL]

Soltesz, F., Szucs, D. & Szucs, L. (2010) Relationships between magnitude representation, counting and memory in 4- to 7-year-old children: A developmental study. *Behavioral and Brain Functions* 6:13. doi: 10.1186/1744-9081-6-13. [JP]

Sophian, C. & Chu, Y. (2008) How do people apprehend large numerosities? *Cognition* 107(2):460–78. Available at: http://dx.doi.org/10.1016/j.cognition.2007.10.009. [JP]

St Clair-Thompson, H. L. & Gathercole, S. E. (2006) Executive functions and achievements in school: Shifting, updating, inhibition, and working memory. *Quarterly Journal of Experimental Psychology* 59(4):745–59. doi: 10.1080/17470210500162854. [aTL]

Stancher, G. Rugani, R., Regolin, L. & Vallortigara, G. (2015) Numerical discrimination by frogs (*Bombina orientalis*). *Animal Cognition* 18(1):219–29. [RR]

Starkey, P., Spelke, E. S. & Gelman, R. (1983) Detection of intermodal numerical correspondences by human infants. *Science* 222(4620):179–81. doi: 10.1126/science.6623069. [rTL]

Starkey, P., Spelke, E. S., & Gelman, R. (1990) Numerical abstraction by human infants. *Cognition* 36(2):97–127. doi: 10.1016/0010-0277(90)90001-Z. [rTL]

Starr, A. & Brannon, E. M. (2015) Evidence against continuous variables driving numerical discrimination in infancy. *Frontiers in Psychology* 6:923. [MEL, OR, SS]

Stewart, N. (2009) Decision by sampling: The role of the decision environment in risky choice. *Quarterly Journal of Experimental Psychology* 62(6):1041–62. [CYO]

Stewart, N., Chater, N. & Brown, G. D. A. (2006) Decision by sampling. *Cognitive Psychology* 53(1):1–26. [CYO]

Stewart, N. & Simpson, K. (2008) A decision-by-sampling account of decision under risk. In: *The probabilistic mind: Prospects for Bayesian cognitive science*, ed. N. Chater & M. Oaksford, pp. 261–76. Oxford University Press. [CYO]

Stoianov, I. & Zorzi, M. (2012) Emergence of a “visual number sense” in hierarchical generative models. *Nature Neuroscience* 15:194–96. doi: 10.1038/nn.2996. [IPS, WvW]

Stoianov, I. & Zorzi, M. (2013) Developmental trajectories of numerosity perception. Poster presented at the College de France workshop “Interactions between space, time and number: 20 years of research” (Paris). [IPS]

Stroop, J. R. (1935) Studies of interference in serial verbal reactions. *Journal of Experimental Psychology* 18:643–62. [OR]

Suanda, S. H., Tompson, W. & Brannon, E. M. (2008) Changes in the ability to detect ordinal numerical relationships between 9 and 11 months of age. *Infancy* 13:308–37. [RR].

Szücs, D., Nobes, A., Devine, A., Gabriel, F. C. & Gebuis, T. (2013) Visual stimulus parameters seriously compromise the measurement of approximate number system acuity and comparative effects between adults and children. *Frontiers in Psychology* 4:444. doi:10.3389/fpsyg. 2013.00444. [aTL, DS]

Testolin, A. & Zorzi, M. (2016) Probabilistic models and generative neural networks: Towards an unified framework for modeling normal and impaired neurocognitive functions. *Frontiers in Computational Neuroscience* 10:73. doi: 10.3389/fncom.2016.000731. [IPS]

Thompson, C. A. & Opfer, J. E. (2010) How 15 hundred is like 15 cherries: Effect of progressive alignment on representational changes in numerical cognition. *Child Development* 81(6):1768–86. doi: 10.1111/j.1467-8624.2010.01509.x. [PGS]

Thompson, P. (1982) Perceived rate of movement depends on contrast. *Vision Research* 22(3):377–80. [DCB]

Thorell, L. B., Lindqvist, S., Bergman Nutley, S., Bohlin, G. & Klingberg, T. (2009) Training and transfer effects of executive functions in preschool children. *Developmental Science* 12:106–13. [MI]

Tokita, M. & Ishiguchi, A. (2010) How might the discrepancy in the effects of perceptual variables on numerosity judgment be reconciled? Attention, Perception & Psychophysics 72(7):1839–53. doi: 10.3758/APP.72.7.1839. [aTL]

Tokita, M. & Ishiguchi, A. (2013) Effects of perceptual variables on numerosity comparison in 5–6-year-olds and adults. *Frontiers in Psychology* 4:431. doi: 10.3389/fpsyg.2013.00431. [aTL, JP]

Treisman, A. M. & Gelade, G. (1980) A feature-integration theory of attention. *Cognitive Psychology* 12(1): 97–136. [OR]

Trick, L. M. & Pylyshyn, Z. W. (1994) Why are small and large numbers enumerated differently? A limited-capacity preattentive stage in vision. *Psychological Review* 101(1):80. [RM]

Tudusciuc, O. & Nieder, A. (2007) Neuronal population coding of continuous and discrete quantity in the primate posterior parietal cortex. *Proceedings of the National Academy of Sciences of the United States of America* 104(36):14513–18. doi: 10.1073/pnas.0705495104. [aTL, DO]

Tudusciuc, O. & Nieder, A. (2009) Contributions of primate prefrontal and posterior parietal cortices to length and numerosity representation. *Journal of Neurophysiology* 101:2984–94. [AN]

Turati, C., Gava, L., Valenza, E. & Ghirardi, V. (2013) Number versus extent in newborns' spontaneous preference for collections of dots. *Cognitive Development* 28(1):10–20. [MDdH, EM]

Tversky, A. & Kahneman, D. (1992) Advances in prospect theory: Cumulative representation of uncertainty. *Journal of Risk and Uncertainty* 5(4):297–323. [CYO]

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Tzelgov, J., Yehene, V., Kotler, L. & Alon, A. (2000) Automatic comparisons of artificial digits never compared: Learning linear ordering relations. *Journal of Experimental Psychology: Learning, Memory and Cognition* 26(1):1–18. [OR]

Ungemach, C., Stewart, N. & Reimers, S. (2011) How incidental values from the environment affect decisions about money, risk, and delay. *Psychological Science* 22(2):253–60. [CYO]

Valenza, E., Leo, I., Gava, L. & Simion, F. (2006) Perceptual completion in newborn human infants. *Child Development* 77(6):1810–21. [MDdH, SFL]

Vallentin, D. & Nieder, A. (2008) Behavioral and prefrontal representation of spatial proportions in the monkey. *Current Biology* 18(18):1420–25. doi: 10.1016/j.cub.2008.08.042. [PGS]

Vallentin, D. & Nieder, A. (2010) Representations of visual proportions in the primate posterior parietal and prefrontal cortices. *European Journal of Neuroscience* 32(8):1380–87. doi: 10.1111/j.1460-9568.2010.07427.x. [aTL]

Van Opstal, F. & Verguts, T. (2013) Is there a generalized magnitude system in the brain? Behavioral, neuroimaging, and computational evidence. *Frontiers in Psychology* 4:435. [DO]

van Woerkom, W. (2016) Modelling the visual *number sense* using a deep generative neural network. Unpublished research report, University of Amsterdam. [WvW]

Verguts, T. & Fias, W. (2004) Representation of number in animals and humans: A neural model. *Journal of Cognitive Neuroscience* 16(9):1493–504. doi: 10.1162/0898929042568497. [aTL]

Viswanathan, P. & Nieder, A. (2013) Neuronal correlates of a visual “sense of number” in primate parietal and prefrontal cortices. *Proceedings of the National Academy of Sciences of the United States of America* 110(27):11187–92. doi: 10.1073/pnas.1308141110. [aTL, AN]

Viswanathan, P. & Nieder, A. (2015) Differential impact of behavioral relevance on quantity coding in primate frontal and parietal neurons. *Current Biology* 25:1259–69. [AN]

Vuilleumier, P., Armony, J. L., Driver, J. & Dolan, R. J. (2003) Distinct spatial frequency sensitivities for processing faces and emotional expressions. *Nature Neuroscience* 6(6):624–31. doi: 10.1038/nn1057. [DO]

Walasek, L. & Stewart, N. (2015) How to make loss aversion disappear and reverse: Tests of the decision by sampling origin of loss aversion. *Journal of Experimental Psychology: General* 144(1):7–11. [CYO]

Walsh, V. (2003) A theory of magnitude: Common cortical metrics of time, space and quantity. *Trends in Cognitive Sciences* 7(11):483–88. doi: 10.1016/j.tics.2003.09.002. [aTL, DCB, NG, DCH, DO]

Wang, J., Odic, D., Halberda, J. & Feigenson, L. (2016) Changing the precision of preschoolers’ approximate number system representations changes their symbolic math performance. *Journal of Experimental Child Psychology* 147:82–99. [MI]

Wang, J., Odic, D., Halberda, J. & Feigenson, L. (2017) Better together: Multiple lines of evidence for a link between approximate and exact number representations: A reply to Merkley, Matejko, and Ansari. *Journal of Experimental Child Psychology* 153:168–72. [MI]

Watanabe, S. (1998) Discrimination of “four” and “two” by pigeons. *Psychological Record* 4:383–91. [aTL]

Werker, J. F. & Lalonde, C. E. (1988) Cross-language speech perception: Initial capabilities and developmental change. *Developmental Psychology* 24(5):672–83. [OR]

Westermann, G. (2000) A constructivist dual-representation model of verb inflection. In: *Proceedings of the 22nd Annual Conference of the Cognitive Science Society*, ed. L. Gleitman & A. Joshi, pp. 977–82. Erlbaum. [WvW]

Wilcox, T. (1999) Object individuation: Infants’ use of shape, size, pattern, and color. *Cognition* 72:125–66. [SFL]

Wilmer, J. B., Germine, L., Chabris, C. F., Chatterjee, G., Williams, M., Loken, E., Nakayama, K. & Duchaine, B. (2010) Human face recognition ability is specific and highly heritable. *Proceedings of the National Academy of Sciences of the United States of America* 107(11):5238–41. [NG]

Wu, G. & Gonzalez, R. (1996) Curvature of the probability weighting function. *Management Science* 42(12):1676–90. [CYO]

Xu, F. (2003) Numerosity discrimination in infants: Evidence for two systems of representations. *Cognition* 89(1):B15–25. [MDdH]

Xu, F. & Arriaga, R. I. (2007) Number discrimination in 10-month-old infants. *British Journal of Developmental Psychology* 25(1):103–108. doi: 10.1348/026151005X90704. [SS]

Xu, F. & Carey, S. (1996) Infants’ metaphysics: The case of numerical identity. *Cognitive Psychology* 30(2):111–53. [EM, KSM]

Xu, F. & Spelke, E. S. (2000) Large number discrimination in 6-month-old infants. *Cognition* 74(1):B1–11. doi: 10.1016/S0010-0277(99)00066-9. [MDdH, MEL, SS]

Xuan, B., Zhang, D., He, S. & Chen, X. (2007) Larger stimuli are judged to last longer. *Journal of Vision* 7(10):2 1–5. doi: 10.1167/7.10.2. [DCB]

Yovel, G. & Kanwisher, N. (2004) Face perception: Domain specific, not process specific. *Neuron* 44:889–98. [NG]

Zauberman, G., Kim, B. K., Malkoc, S. A. & Bettman, J. R. (2009) Discounting time and time discounting: Subjective time perception and intertemporal preferences. *Journal of Marketing Research* 46(4):543–56. [CYO]

Zentall, S. S., Smith, Y. N., Lee, Y. B. & Wieczorek, C. (1994) Mathematical outcomes of attention-deficit/hyperactivity disorder. *Journal of Learning Disabilities* 27(8):510–19. doi:10.1177/002221949402700806. [NCJ]

Zhu, Q., Song, Y., Hu, S., Li, X., Tian, M., Zhen, Z., Dong, Q., Kanwisher, N. & Liu, J. (2010) Heritability of the specific cognitive ability of face perception. *Current Biology* 20(2):137–42. [NG]

Zorzi, M., Testolin, A. & Stoianov, I. P. (2013) Modeling language and cognition with deep unsupervised learning: A tutorial overview. *Frontiers in Psychology* 4:515. doi: 10.3389/fpsyg.2013.00515. [IPS]

Zuidema, W. &, and Bart de Boer, B. (2014) Modeling in the language sciences. In: *Research methods in linguistics*, ed. R. Podesva & D. Sharma, pp. 422–39. Cambridge University Press. [WvW]

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