Published in final edited form as:
Cognition. 2011 November 1; 121(2): 253–255. doi:10.1016/j.cognition.2011.04.002.

Sensitivity to number: Reply to Gebuis and Gevers

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Abstract

Past research showing a bias towards the larger non-symbolic number by adults and children in line bisection tasks (de Hevia & Spelke, 2009) has been challenged by Gebuis and Gevers, suggesting that area subtended by the stimulus and not number is responsible for the biases. I review evidence supporting the idea that although sensitivity to number might be relatively affected by visual cues, number is a major, salient property of our environment. The influence of non-numerical cues might be seen as the concurrent processing of dimensions that entail information of magnitude, without implying that number is constructed out of those dimensions.

Keywords

number; non-numerical cues; line bisection; spatial biases

In a series of three experiments, Gebuis and Gevers first replicate initial findings made by de Hevia and Spelke (2009) of a systematic bias towards the larger number in a line bisection task with non-symbolic numerical flankers (arrays of dots), while in the final experiment they manipulate the area subtended by the flankers, and report a bias towards the smaller number (which occupies a larger subtended area). With their work, Gebuis and Gevers open a discussion on the effect of visual cues on number processing, and on which are the dimensions of magnitude that are considered relevant when the 'larger' of two stimuli is spontaneously determined.

In previous reports adults showed a bias towards the larger number when bisecting a line flanked by Arabic digits (de Hevia, Girelli, & Vallar, 2006; Fischer, 2001), while non-symbolic number was used in de Hevia and Spelke to investigate spatial biases related to number in children and adults. In this study, a bias towards the larger number was systematically observed after controlling each of these variables in separate experiments: total area, total contour length, and gap between the line and the flankers. When identical black circles enclosed the dots arrays, providing a strong cue for equal subtended areas in both flankers, bisection was again biased towards the larger number. Moreover, the spatial biases shown by adult participants were equal irrespective of the notation used (Arabic and arrays of dots), in line with the view of an abstract numerical representation common to numbers in any notation or modality (Barth, Kanwisher, & Spelke, 2003; Piazza, Pinel, Le Bihan, & Dehaene, 2007).

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In their study, Gebuis and Gevers report the same results for Experiments 1 and 2 after controlling for total area and total contour length, respectively, while in Experiment 3 a bias towards the smaller number is found. In their three experiments, the bias is found towards the array of dots that occupies a larger subtended area. When spatial biases related to number were previously reported with Arabic numbers as flanking stimuli (de Hevia et al., 2006; Fischer, 2001), the ‘problem’ of controlling for continuous variables that usually co-vary with number was absent. However, the study by Gebuis and Gevers suggests that when non-symbolic number is used, participants are not only sensitive to these non-numerical cues, but can even base their magnitude judgments on them. To better characterize numerical processing, research is needed on the conditions that favor numerical vs. non-numerical magnitude information. Eventually, this will provide valuable information on how one type of magnitude information can enhance processing of number.

The line bisection task can indeed offer a practical tool to evaluate the spontaneous weighing that is given to information of quantity in a visuo-spatial task: when using numbers, a bias towards the larger one is expected. But not all types of quantity information behave equally in this task. For instance, the ‘Baldwin Illusion’ (Baldwin, 1896), a well-known optical illusion, exemplifies the role played by differences in area (or size). In this illusion a line flanked by two squares of unequal size is bisected towards the flanker of smaller size. That is, spatial biases related to physical magnitude and to numerical magnitude emerge in opposite directions. Moreover, the spatial biases related to both physical and numerical magnitude emerge with both symbolic as well as non-symbolic stimuli: when physical size is represented symbolically, by flanking each side of the line with (equally-sized) images of an elephant and a bird, a bias towards the smaller animal is found, just as the Baldwin illusion would work (Girelli, Perrone, Pisacane, & Macchi Cassia, 2009). Thus, with the line bisection task, the mapping of number on space appears to operate in a different way from the mapping of size on space.

Gebuis and Gevers argue that since non-symbolic stimuli are constructed from different visual cues, numerosity has to be extracted by combining the different cues present in the display. However, if non-numerical visual cues contribute to the extraction of numerosity, why would these cues be more important than numerosity itself? One possibility is that when most of visual cues present in a numerical display ‘counteract’ the numerical information, participants might find magnitude information other than number more informative as a path towards selecting ‘bigger magnitude’. This might be especially true in a speeded visuo-spatial task where number is irrelevant to the task at hand. This hypothesis would be in line with the idea that, depending on the context, we can process both number independently, and in conjunction with all the information of magnitude available from non-numerical continuous cues. Although we take for granted that number is automatically processed in a visual array of dots, as shown by different studies (e.g., Cantlon, Brannon, Carter, & Pelphrey, 2006; Piazza, Izard, Pinel, Le Bihan, & Dehaene, 2004; Piazza, Pinel, Le Bihan, & Dehaene, 2007), it is still possible that in the line bisection task with non-symbolic number the numerical information was not extracted, and thus its influence on the spatial biases was absent.

Furthermore, from what the Baldwin illusion teaches us (i.e., a bias towards the smaller area, which is opposite to the account of Gebuis and Gevers), area subtended by the flankers alone might not be the variable guiding behavior in Gebuis and Gevers’ experiments. At least not the only one. As the authors suggest, one could rely on the most prominent cue in a display, or on the cue that differs most between two displays. In their experiments, the flankers’ difference in area subtended is less salient than the difference in number, and even than the difference in dot size. Assuming that number was extracted efficiently in Experiment 3, for instance, larger dot size together with larger subtended area (of the 2-dot array) might have signaled 'bigger' to participants, thus overriding the numerical information as a confident source for making this judgment. In fact, when encountering small numbers, as in the case of the 2-dot array, subjects track and encode the features of those individuals, such as shape and area, in parallel (see, for instance, Hyde & Spelke, 2009). Similarly, in Experiments 1 and 2, number might indeed have had an effect on the spatial biases. In sum, different sources of magnitude information (e.g., different numbers together with different dot sizes, overall areas, and subtended areas) might explain the spatial biases by different accounts.

How is the numerical and non-numerical information of magnitude present in a visual display processed? On the one hand, as noted by Gebuis and Gevers, in some conditions numerical judgments are influenced by visual cues (e.g., Sophian & Chu, 2008). On the other hand, recent evidence suggests that estimated numerosity is an independent primary visual property, not reducible to others. Burr and Ross (2008) have shown that perceived numerosity is susceptible to adaptation like other primary visual properties of the scene, suggesting that the visual system outputs, among other properties, number (for a debate on whether these effects reflect adaptation to number or to density, see Durgin, 2008). Yet, empirical evidence has shown that congruency in the available information of magnitude, numerical and non-numerical, indeed enhances numerical processing. Infants, children, and adults have been shown to beneficiate from the congruency between different sources of magnitude (as exemplified, for instance, in the *Stroop* paradigm with children and adults, e.g., Girelli, Lucangelli, & Butterworth, 2000; for infants, see Suanda, Tompson, & Brannon, 2008), suggesting that the presence of redundant information of magnitude adds up to form a stronger representation.

To support non-verbal numerical representation, we can make use of two distinct cognitive systems that operate over discrete elements; one for the exact representation of small sets and another for approximate representations of large number (see Feigenson, Dehaene, & Spelke, 2004). The two systems relate to non-numerical continuous variables: they are tracked for small sets (e.g., Feigenson & Carey, 2003) and related to large number through a mapping process (de Hevia & Spelke, 2010; Lourenco & Longo, 2010). However, the idea that non-continuous quantitative variables such as area are more primitive dimensions than number and therefore guide behavior, especially in infants and children, is challenged by available evidence. Infants, and even rhesus monkeys, prioritize number when they can use either of two dimensions (like number and area, or number and shape) to effectively perform the task (Cantlon & Brannon, 2007; Cordes & Brannon, 2009). Importantly, these results are obtained under conditions of 'spontaneous' behavior. Moreover, numerosity might be easier to process than area. Six-month-old infants detect a numerosity change when previously habituated to displays where area varies widely (Xu & Spelke, 2000), and they succeed with an area change when it is represented by a single figure (Brannon, Lutz, & Cordes, 2006). They fail, however, at detecting a change in area when number varies widely in habituation (Brannon, Abbott, & Lutz, 2004). This suggests that when number is available in a display it is spontaneously extracted and can actually interfere with the processing of a seemingly more basic visual property, such as area.

The fact that visual cues are taken into account during number processing does not entail that extraction of number relies upon other information of magnitude, nor does it entail that our ability to process number results from the weighing of those cues. Effects of non-numerical cues on number processing inform us that numerical magnitude is not an isolated representation. Instead, number connects to other representations of magnitude. In fact, one pressing question is whether the neural system that supports approximate numerical representation is shared with other continuous dimensions of magnitude (see Cantlon, Platt, & Brannon, 2009). If we assume that number is a basic feature of the environment, and the existence of a specialized system tuned to it that is engaged when discrete elements are encountered, then the effects of (visual) non-numerical cues can be seen as the influence from other dimensions that also entail information of magnitude. The fact that reliance upon visual cues decreases with age (Halberda & Feigenson, 2008) might signal that adults are more efficient than young children in inhibiting other information of magnitude that is automatically extracted in a numerical display (Soltesz, Szucs, & Szucs, 2010). Finally, the acuity of the representations of numerical magnitude might not depend on the weighing process given to the non-numerical cues that co-vary with number, as suggested by Gebuis and Gevers, but on the practice acquired with symbolic numbers and/or maturational aspects (see Piazza, in press).

References

Baldwin JM. The effect of size-contrast upon judgements of position in the retinal field. Psychological Review. 1895; 2:244–259.

Barth H, Kanwisher N, Spelke ES. The construction of large number representations in adults. Cognition. 2003; 86:201–221. [PubMed: 12485738]

Brannon EM, Abbott S, Lutz DJ. Number bias for the discrimination of large visual sets in infancy. Cognition. 2004; 93:B59–B68. [PubMed: 15147939]

Brannon EM, Lutz D, Cordes S. The development of area discrimination and its implications for number representation in infancy. Developmental Science. 2006; 9:F59–F64. [PubMed: 17059447]

Burr D, Ross J. A visual sense of number. Current Biology. 2008; 18:425–428. [PubMed: 18342507]

Cantlon JF, Brannon EM. How much does number matter to a monkey (macaca mulatta)? Journal of Experimental Psychology: Animal Behavior Processes. 2007; 33:32–41. [PubMed: 17227193]

Cantlon JF, Brannon EM, Carter EJ, Pelphrey K. Functional imaging of numerical processing in adults and 4-year-old children. PLOS Biology. 2006; 4:e125. [PubMed: 16594732]

Cantlon JF, Platt ML, Brannon EM. Beyond the number domain. Trends in Cognitive Sciences. 2009; 13:83–91. [PubMed: 19131268]

Cordes S, Brannon EM. The relative salience of discrete and continuous quantity in young infants. Developmental Science. 2009; 12:453–463. [PubMed: 19371370]

de Hevia MD, Girelli L, Vallar G. Numbers and space: A cognitive illusion? Experimental Brain Research. 2006; 168:254–264.

de Hevia MD, Spelke ES. Spontaneous mapping of number and space in adults and young children. Cognition. 2009; 110:198–207. [PubMed: 19095223]

de Hevia MD, Spelke ES. Number-space mapping in human infants. Psychological Science. 2010; 21:653–660. [PubMed: 20483843]

Durgin FH. Texture density adaptation and visual number revisited. Current Biology. 2008; 18:R855–R856. [PubMed: 18812077]

Feigenson L, Carey S. Tracking individuals via object-files: Evidence from infants' manual search. Developmental Science. 2003; 6:568–584.

Feigenson L, Dehaene S, Spelke ES. Core systems of number. Trends in Cognitive Sciences. 2004; 8:307–314. [PubMed: 15242690]

Fischer MH. Number processing induces spatial performance biases. Neurology. 2001; 57:822–826. [PubMed: 11552011]

Girelli L, Lucangeli D, Butterworth B. The Development of Automaticity in Accessing Number Magnitude. Journal of Experimental Child Psychology. 2000; 76:104–122. [PubMed: 10788305]

Girelli, L.; Perrone, G.; Pisacane, A.; Cassia, V. Macchi Poster presented at the SRCD meeting. Denver; Colorado, USA: 2009. The influence of number and magnitude information on space representation in children.

Halberda J, Feigenson L. 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. 2008; 44:1457–1465. [PubMed: 18793076]

Hyde DC, Spelke ES. All numbers are not equal: An electrophysiological investigation of small and large number representations. Journal of Cognitive Neuroscience. 2009; 21:1039–1053. [PubMed: 18752403]

Lourenco SF, Longo MR. General magnitude representation in human infants. Psychological Science. 2010; 21:873–881. [PubMed: 20431048]

Piazza M, Izard V, Pinel P, Le Bihan D, Dehaene S. Tuning curves for approximate numerosity in the human intraparietal sulcus. Neuron. 2004; 44:547–555. [PubMed: 15504333]

Piazza M, Pinel P, Le Bihan D, Dehaene S. A magnitude code common to numerosities and number symbols in human intraparietal cortex. Neuron. 2007; 53:293–305. [PubMed: 17224409]

Piazza M. Neurocognitive start-up tools for symbolic number representations. Trends in Cognitive Science. (in press).

Soltesz F, Szucs D, Szucs L. Relationships between magnitude representation, counting and memory in 4- to 7-year-old children: A developmental study. Behavioral and Brain Functions. 2010; 6:13. [PubMed: 20167066]

Sophian C, Chu Y. How do people apprehend large numerosities? Cognition. 2008; 107:460–478. [PubMed: 18082157]

Suanda SH, Tompson W, Brannon EM. Changes in the ability to detect ordinal numerical relationships between 9 and 11 months of age. Infancy. 2008; 13:308–337. [PubMed: 20703362]

Xu F, Spelke ES. Large number discrimination in 6-month-old infants. Cognition. 2000; 74:B1–B11. [PubMed: 10594312]