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Dissociation between line bisection and mental-number-line bisection in healthy adults

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ABSTRACT

Healthy adults bisect visual horizontal lines slightly to the left of their true center. This bias has been termed "pseudoneglect" and is considered to reflect right hemisphere dominance in the orienting of spatial attention. A previous investigation reported a positive correlation between pseudoneglect and a corresponding negative bias towards numbers lower than the true midpoint, i.e. supposedly to the left of the midpoint, during the mental bisection of number intervals that were defined by two visual arabic digits presented one to the left and one to the right of a horizontal line (Longo and Lourenco, 2007, *Neuropsychologia*, 45, 7, 1400–1407). Here, studying a sample of 60 healthy participants we verified whether this correlation still holds when the endpoints of number intervals are defined verbally, i.e. with no visual-spatial cues suggesting their left-to-right arrangement. Participants bisected horizontal lines (2 cm, 10 cm and 20 cm), short number intervals (3-, 5-, 7- and 9-unit) and large number intervals (16-, 24-, 32-, 40-, 48-, 56-, and 64-unit). Pseudoneglect was observed both in line and number interval bisection, confirming the results of Longo and Lourenco (2007). Nonetheless, the study of correlations between bisection biases averaged across different line and number intervals lengths and between all possible pairings of line and number interval lengths revealed no significant or systematic pattern. During line bisection pseudoneglect increased as a function of line length while with short number intervals pseudoneglect decreased and turned into an opposite positive bias as a function of interval length. With large number intervals no linear relationship was present between bisection bias and interval length and, as in Longo and Lourenco (2007), the higher was the starting point of the number interval the larger was pseudoneglect. These results show that verbally defined number intervals are not mentally inspected with the same mechanisms that are engaged by the bisection of horizontal visual lines. This suggests that number intervals are not inherently arranged along the mental equivalent of a left-to-right oriented horizontal line. This spatial representation seems rather adopted when, as in the case of the SNARC task, "left" vs. "right" codes must be used for the selection of responses associated with numbers or when, as in the case of Longo and Lourenco (2007), the numerical material to be processed is arranged in left-to-right order.

1. Introduction

The discovery that in a task requiring the choice between a left and a right button press, left-to-right readers decide faster with the left button that a number is smaller than 5 (or that a number smaller than 5 is odd or even) and decide faster with the right button that a number is higher than 5 (or that a number higher than 5 is odd or even; Spatial-Numerical Association of Response Codes = SNARC; Dehaene et al., 1993), has led to the widespread assumption that number magnitudes have an inherent mental spatial representation that conforms to cultural reading styles, so that in western cultures smaller numbers are represented to the left or larger ones on a horizontal mental number line (MNL). The strength and reliability of the SNARC effect, has promoted the development of several lines of inquiry that exploit and explore the functional and anatomical links between the mechanisms underlying the representation of number magnitudes and those underlying the representation of space and the orienting of spatial attention. In the neuropsychological domain, it was suggested that

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right brain damaged patients (RBD) suffering defective attention for the left side of space, i.e. left spatial neglect, also suffer a similar deficit when they set mentally without formal calculation the midpoint of number intervals that are defined verbally by an examiner (Zorzi et al., 2002). A shift of the subjective midpoint of 5-, 7- and 9-unit number intervals toward numbers higher than the true midpoint (e.g. midpoint between 1 and 9=7 instead of 5) was initially observed in a relatively small sample of neglect patients, just as if these patients were not paying attention to smaller numbers on the left side of number intervals. The phenomenological similarity between spatial and numerical impairments, was made even more captivating by the finding that a paradoxical bias toward numbers lower than the real midpoint, i.e. putatively to the left of the midpoint, was found in the mental bisection of short 3-unit number intervals, just like it is sometime found when neglect patients bisect very short visual horizontal lines (i.e. “cross-over" effect; Doricchi et al., 2005a). Nonetheless, in these initial observations the association between the bias in the mental bisection of number intervals and the bias in the bisection of horizontal visual lines was not empirically tested. Several studies have now investigated this issue and have clarified that the pathological bias in the bisection of number intervals is unrelated to the presence of a similar bias in the bisection of visual lines and is dissociated from the presence and severity of left side neglect in visual or imagery space (Rossetti et al., 2004; Doricchi et al., 2005b; 2009; Loetscher and Brugger, 2009; Loetscher et al., 2010; van Dijck et al., 2011a; 2011b; Rossetti et al., 2011; Aiello et al., 2012; 2013; Pia et al., 2012; Storer and Demeyere, 2014). More recently, in two independent investigations (both reported in Aiello et al. (2012)) it was rather found that RBD patients who suffer a pathological bisection bias toward numbers higher than the midpoint of number intervals also suffer an equivalent pathological bias when the same intervals are treated as time-intervals on a mental clock face, so that the spatial organization of intervals is reversed and higher time-numbers are represented on the left side, not right side, of the mental layout. These findings point at a dissociation between numerical and spatial-attentional biases and suggest that right brain damage disrupts the abstract representation of small numerical magnitudes, thus creating a corresponding bias toward larger magnitudes, independently from the mapping of small magnitudes on the left or the right side of a mental layout.

Based on these findings, in the present study we wished to reinvestigate the functional association, or dissociation, between numerical and spatial biases by examining whether the error bias displayed by healthy participants in the bisection of visual horizontal lines is correlated with an equivalent bias in the mental bisection of number intervals whose endpoints are defined verbally. To this aim, we capitalized on the findings from a previous study by Longo and Lourenco (2007). These authors documented a significant correlation between the small leftward bias, termed “pseudoneglect”, that is typically observed in the line bisection performance of healthy adult participants (Jewell and McCourt, 2000) and a bias towards numbers smaller than the midpoint, i.e. putatively to the left of the midpoint, during the mental bisection of number intervals whose endpoints were presented visually, one to the left and one to the right of a short horizontal line. We hypothesized that if a left-to-right spatial arrangement is inherent to number magnitudes, then a correlation between the performance in the line and number interval bisection tasks should be found even when number intervals are defined verbally with no spatial cuing provided by the arrangement of interval endpoints to the left and to the right of a visual horizontal line. On the contrary, if the mental left-to-right arrangement of intervals is strategically triggered by the left-to-right visual spatial arrangement of numbers defining the interval endpoints, no equivalent correlation should be found when number intervals are presented in a purely verbal manner.

2. Material and methods

2.1. Participants

60 healthy right-handed participants (40 females, 20 males, mean age= 21.9 y) were examined in the present investigation. Supplementary data gathered from a different sample of 31 participants to a previous study (Doricchi et al., 2009) were also included in the analyses of the “Line Bisection” task, the “Mental Bisection of Short Number Intervals” and in the study of the correlation between these two tasks (see below).

The handedness of participants was assessed with the Italian adaptation (Salmaso and Longoni, 1985) of the Oldfield questionnaire (Oldfield, 1971). In this questionnaire a laterality quotient (LQ) equal to +100 indicates complete right-hand dominance whereas an LQ of −100 indicates complete left-hand dominance. The LQ was + 82.4 (s.d.=5.3) in the overall sample of 91 participants, +89.6 (s.d.=10.6) in the sample 60 participants examined in the present investigation and +93.1 (s.d.=10.4) in the sample of 31 participants gathered from our previous study (Doricchi et al., 2009). The LQ was comparable between the samples of 60 and 31 participants ($t_{(1,\ 89)}=-1.5$, $p>.05$).

2.2. Tasks

2.2.1. “Line bisection”

Participants marked with a fine line pencil the subjective center of horizontal lines that were individually printed at the center of a horizontally oriented A4 paper sheet. Lines were 2 cm, 10 cm or 20 cm long. Three trials per line length were administered. The sheet was presented at the center of a table, with its center aligned to the head-body mid-sagittal plane of participants. Individual bisection deviations from the objective center of lines were measured to the closest 0.5 mm. Rightward deviations from the objective line center were coded as positive ones and leftward deviations as negative ones.

2.2.2. “Mental Bisection of Short Number Intervals”

In this task, participants were asked to speak out the midpoint of number intervals without making arithmetic calculations, thus providing an “approximate” bisection of intervals. In each trial two numbers defining the beginning and the end of 3-unit (e.g. 4–6), 5-unit (e.g. 3–7), 7-unit (e.g. 2–8) and 9-unit number intervals (e.g. 1–9) were presented through headphones. Intervals were taken from equivalent positions across the first three decades (e.g. 4-6, 14-16, 24-26; the complete list of intervals is reported in Supplementary Table 1). In the first part of the task, intervals were presented in ascending order (48 trials) and in the second part in descending order (48 trials). Bisection deviations toward numbers higher than the interval midpoint were scored as positive ones and deviations toward numbers lower than the midpoint as negative ones.

2.2.3. “Mental Bisection of Large Number Intervals”

This task was performed only by the 60 participants to the present study and was equivalent to the preceding task, except from the length of number intervals. In analogy to the study by Longo and Lourenco (2007) larger 16-, 24-, 32-, 40-, 48-, 56-, and 64-unit intervals were presented. For each interval length, a pool of intervals was prepared taking as starting point of intervals different consecutive number positions over consecutive decades. The lower starting point of all intervals was 10 and the highest