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NEUROBEHAVIORAL GRAND ROUNDS

Visual Neglect in Horizontal and Radial Space: When Left Goes Right, Proximal Goes Distal

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Abstract

Hemi-spatial neglect can manifest in both the horizontal and radial spatial plane. However, debate exists over how closely the two forms of neglect relate. Here we compared the ability of a neglect patient to bisect stimuli in horizontal *versus* radial orientation. When oriented horizontally, single lines were mis-bisected to the right, yet when surrounded by visual distracters, the lines were mis-bisected to the left. A leftward bias also emerged when horizontally aligned strings of symbols were bisected. Unexpectedly, an analogous pattern of bias appeared when the stimuli were bisected in radial orientation; stimuli that induced a leftward bias now induced a proximal bias, while stimuli that induced a rightward bias induced a distal bias. Spontaneous reversals in radial bias have not been previously reported, and given that they were coupled with the horizontal reversals, suggest that the spatial boundaries of horizontal and radial neglect are strongly constrained by common stimulus configurations. (*JINS*, 2011, *17*, 1–5)

Keywords: Ipsilesional, Contralesional, Attention, Stimulus bisection, Perceptual disorder, Cerebral hemisphere

INTRODUCTION

Visual neglect is most often characterized by the failure to acknowledge or respond to visual stimuli that appear on the side of space opposite the brain lesion. Many clinical practitioners regard the uni-directional nature of horizontal neglect as a defining characteristic. However, a minority of sufferers show a bi-directional pattern of impairment within peri-personal space, neglecting the left-side under some conditions and the right-side under others. Cases include those who ignore the left-hand side of displays when reading but the right side during copying and drawing (Humphreys & Riddoch, 1995), or ignore the left side during picture naming, but the right side when spelling (Riddoch, Humphreys, Luckhurst, Burroughs, & Bateman, 1995). This reversible spatial bias is taken to reflect a quality that runs to the heart of neglect. Namely, that the spatial boundaries of neglect are not fixed, and rather determined by a host of leftward and rightward vectors that seek to push behavior in opposing directions (see Kinsbourne, 1993).

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The main drivers of these left and right vectors are commonly attributed to processes that elicit a contralateral bias within the right and left cerebral hemispheres respectively. The strength of hemispheric bias is influenced by numerous factors following brain injury, including the overall level of hemispheric activation (Kinsbourne, 1993), the relative integrity of attentional and intentional control processes (Butters, Rapcsak, Watson, & Heilman, 1988), as well as the degree to which specific lateralised processes are engaged by both task and stimulus factors (see Varnava, McCarthy, & Beaumont, 2002).

The main aim of the present study was to investigate whether the spatial reversals seen in horizontal neglect are also apparent within the radial (i.e., proximal/distal) plane of peri-personal space. That is, whether the boundaries of radial neglect are shaped by the same kind of directionally opposed, competitive interactions that mediate horizontal neglect.

The question arises because those cases of radial neglect so far reported have shown either a distal *or* proximal bias (e.g., Coslett, Schwartz, Goldberg, Hass, & Perkins, 1993; Halligan & Marshall, 1993; Shelton, Bowers, & Heilman, 1990), as opposed to a bias that switches between distal *and* proximal. However, the failure to observe spatial reversals within the radial plane may reflect the limited range of stimuli presented than the absence of directionally opposed biases. This is because most studies have probed radial bias using only a single type of stimulus (usually lines) of relatively constant size. Yet we know from individuals who switch between left and right neglect that the physical appearance of stimuli is a key determinant of directional bias. For example, individuals who show ipsilesional neglect during line bisection can show contralesional neglect when horizontally aligned strings of alphanumeric characters are bisected (Na et al., 2000). Likewise, the left side of displays can be neglected when the component parts cohere into a single emergent object, while the right side is neglected when a more random arrangement is perceived (Humphreys & Riddoch, 1995).

In the current study, we investigated the behavior of an individual who at initial screening showed spatial reversals within the horizontal plane; during daily ward activity he showed a persistent right neglect, yet during line bisection he showed left neglect. Assuming that these horizontal reversals could be replicated under experimental conditions, the question arose as to whether these were accompanied by analogous reversals in the radial plane. If found to be the case then, aside from showing for the first time that the spatial boundaries of radial neglect can spontaneously reverse, strong evidence would have been gained for the idea that common mechanisms guide the deployment of attention across horizontal and radial space (see Barrett & Craver-Lemley, 2008; Heilman, Chatterjee, & Doty, 1995; Previc, 1990).

CASE NOTES

Patient C.P., a 57-year-old, left-handed (as determined by the Briggs and Nebes Handedness questionnaire—1975) man presented with right hemi-inattention, a non-fluent Broca's aphasia with oral and verbal dyspraxia, and a sublux right shoulder and flaccidity in his right upper limb consistent with a cortico-spinal lesion. His computed tomography (CT) scans revealed bilateral brain lesions (see Figure 1).

Following institutional ethics approval and written informed consent, C.P. was recruited to the present study 6 weeks post-onset, at which time he still showed a rightward neglect during daily ward routine. However, his performance on subtests of the Behavioral Inattention Test (Wilson, Cockburn, & Halligan, 1987) showed a more complex neglect that incorporated both contralesional and ipsilesional elements. He marked only 7 (all left-sided) of the 36 lines during the line-crossing task, cancelled only 10 (all left-sided) of all 54 stars during star cancellation, and omitted the rightmost figure during the shape copying task. On the picture scanning task, C.P. reported all details on the left-hand side of pictures, but failed to report at least two details from the right-side of each picture. In stark contrast, C.P. bisected 3 lines (each 20.4 cm long) 2.2 cm ($SD = 1.4$ cm) to the right of center.

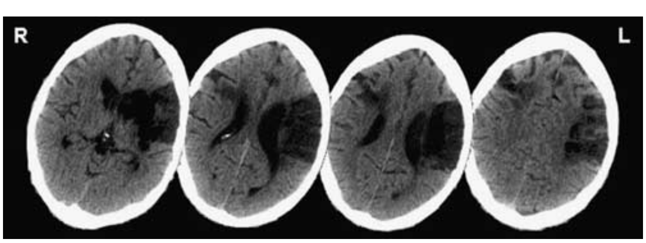

Fig. 1. Computed tomographic (CT) scan acquired 6 months post-onset. The selected sections depict bilateral middle cerebral artery distribution infarcts, with the left-sided infarct involving the basal ganglia and anterior limb of the internal capsule. CT images acquired 2 days after the patient was admitted for the acute left infarct indicated that the right lesion had been acquired some weeks beforehand.

Formal tests of visual extinction were not conducted, and visual field perimetry testing was reported as unreliable.

Experiment 1: Bisection in the Horizontal Plane

The aim of Experiment 1 was to identify a set of stimulus manipulations that reversed the direction of C.P.'s horizontal neglect. Based on studies reviewed above (Humphreys & Riddoch, 1995; Na et al., 2000; Riddoch et al., 1995), we administered a bisection task in which the physical dimensions and configuration of stimuli were manipulated. Assuming that these stimulus changes reversed the direction of bias, it would then be possible (in a second experiment) to re-orient stimuli along the radial plane to determine if a similar reversal occurred during radial bisection.

Method

C.P. was asked to bisect three different types of stimuli; (1) "solid lines" (i.e., those conventionally used in line bisection studies), (2) "symbol lines" composed of horizontally aligned alphanumeric characters and geometric shapes resembling those used by Na et al. (2000), and (3) "lines with distracters" in which a solid line appeared amongst shorter, randomly oriented lines. The three types of to-be-bisected stimuli appeared at five different lengths ranging from 20.8 to 23.3 cm. Solid lines were 1 mm high while the symbol lines were 8 mm high. The distracters in the "lines with distracters" stimuli varied in length from 2.5 cm to 10 cm, were 0.5 mm wide, and varied in number from 12 to 24 with an equal number positioned in random orientation to the left/right of center, and above/below center.

Each stimulus appeared black on a white A4 sheet of paper, and was positioned on a desk approximately 30 cm from participants (i.e., within peri-personal space), aligned with the mid-sagittal plane.

Three blocks of trials were administered, one for each stimulus type. Solid lines were first bisected, followed by the symbol lines, and then the lines with distracters. The order of stimuli within each block was randomized, and each stimulus type was bisected 12 times. The experimenter sat directly opposite the patient throughout, and on handing the patient each sheet of paper asked him to "mark the midpoint," using the pen provided. To provide a normative baseline, 6 female and 5 male, left-handed, neurologically healthy volunteers, mean age 51 (SD 12 years), were also tested.

Results

C.P. mis-bisected the solid lines 2.5 cm to the right, while the symbol lines and lines with distracters were mis-bisected 2.1 cm and 1.6 cm to the left, respectively (see Figure 2a). Bonferroni-corrected pair-wise t tests ($\alpha = 0.016$) showed that the bisection scores for lines were significantly different to those for the symbol lines, ($t(1,11) = 4.7$; $p = .01$) and lines with distracters, ($t(1,11) = 7.5$; $p < .01$). The mean difference between symbol lines and lines with distracters did not reach significance, ($t(1,11) = 0.8$; $p > .05$).

Ninety-five percent prediction intervals derived from the normative control sample indicated that all stimuli were bisected with an accuracy that fell outside normal limits, confirming the pathological nature of C.P.'s horizontal bisection performance. The controls bisected all stimuli relatively accurately (within 0.3 cm of mid-line) showing no significant pair-wise differences (all t scores < 1.5).

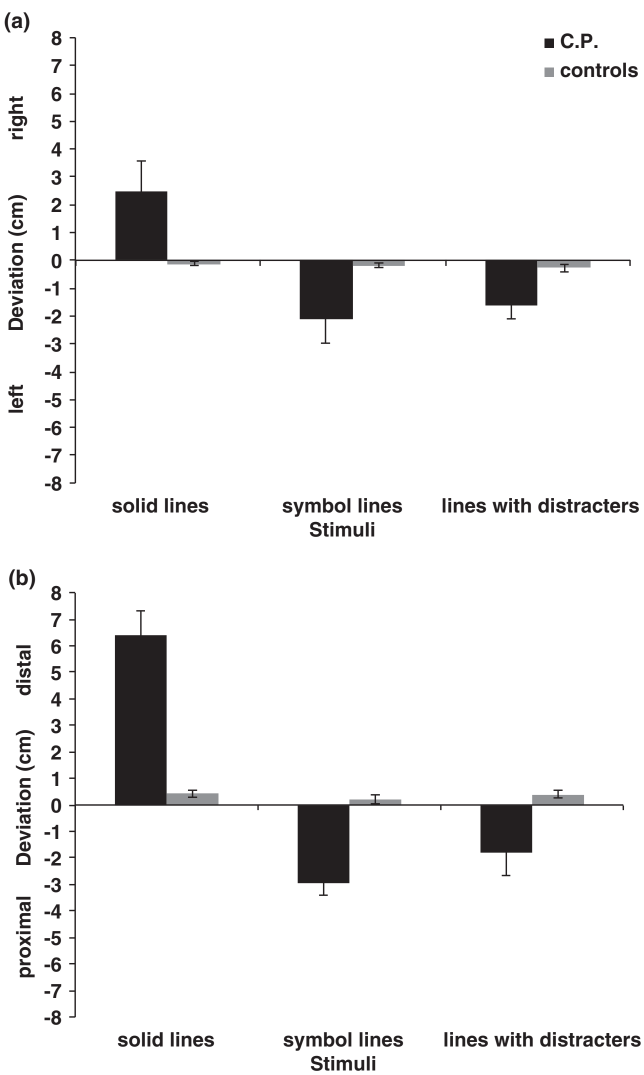

Fig. 2. Mean bisection accuracy (with standard deviation bars) in (a) Experiment 1, and (b) Experiment 2. In the top panel, negative displacements represent leftward error and positive displacements represent rightward error. In the bottom panel, negative displacements represent proximal error and positive displacements represent distal error.

Discussion

As anticipated, the direction of bisection error in patient C.P. could be reversed by altering the configuration of stimuli, solid lines were mis-bisected to the right, while the other two stimulus forms were mis-bisected to the left. The change in directional bias could not be explained by a change in responding hand (Halligan, Manning, & Marshall, 1991), start side (Humphreys & Riddoch, 1995), line length (Monagan & Shillcock, 1998) or upper/lower visual field placement (Geldmacher & Heilman, 1994), all of which were held constant. Although we cannot determine which particular stimulus property (e.g., number of perceptual items, physical dimensions) reversed the direction of bisection error, we have nevertheless identified conditions that capture C.P.'s bi-directional neglect within the horizontal plane. We could now test whether an analogous deficit occurred when the stimuli were oriented along the radial axis.

Experiment 2: Bisection in the radial plane

In Experiment 2 (conducted the next day), we re-administered the above bisection tasks along the radial plane to gauge the specificity of C.P.'s bi-directional neglect.

Methods

As above, except that all A4 stimulus sheets were rotated 90° anti-clockwise to appear in portrait orientation.

Results

C.P. mis-bisected solid lines 6.5 cm distal to center, while the symbol lines and lines with distracters were mis-bisected 3 cm and 1.8 cm proximal to center, respectively (see Figure 2b). Bonferroni-corrected pair-wise t tests ($\alpha = 0.016$) showed the difference between the solid lines and symbol lines ($t(1,11) = 10.4$; $p < .01$), and solid lines and lines with distracters ($t(1,11) = 15.6$; $p < .01$), to be reliable. The mean difference between symbol lines and lines with distracters did not reach significance, ($t(1,11) = 1.9$; $p > .05$).

Ninety-five percent prediction intervals derived from the normative control sample indicated that all stimuli were bisected with an accuracy that fell outside normal limits, confirming the pathological nature of C.P.'s radial bisection performance. The controls bisected all stimuli relatively accurately (within 0.4 cm of mid-line), showing no significant pair-wise differences (all t scores < 2.1).

Discussion

The results of Experiment 2 provide the first reported case of bi-directional radial neglect; the patient erred distally when bisecting solid lines but proximally when bisecting the lines with distracters and symbol lines. Previous studies have shown that both proximal and distal neglect can occur during bisection (Halligan & Marshall, 1993), but never in the same individual. As in Experiment 1, given that the lines were the same length as the other two stimulus types, we can discount the idea that their distal bisection reflected some form of exaggerated cross-over effect (Monagan & Shillcock, 1998).

GENERAL DISCUSSION

The presence of bi-directional neglect within the horizontal plane has been taken as a compelling endorsement of the view that neglect does not impose rigid left/right boundaries on the allocation of attention, but rather imposes boundaries that, although typically skewed toward one side of space, are malleable and dynamic in nature (Kinsbourne, 1993) The data from patient C.P. indicate that this dynamic, and somewhat dramatic, interplay between directionally opposed vectors can also occur within radial peri-personal space.

Given that the individual had bilateral brain lesions, there is no fool-proof way to discern the specific contribution of either hemisphere. On one hand, the right (and by association distal) neglect could have stemmed from the left-sided lesion, while the left (and by association proximal) neglect could have stemmed from the right-sided lesion. On the other hand, the lesion distribution seen in the right hemisphere gives reason to believe that it was primarily responsible for the direction of horizontal, and by association radial, bias, with the left hemisphere lesion incidental.

We slightly favor the latter account because the frontal distribution of C.P.'s right-sided lesion is consistent with a disinhibition of the contralesional approach tendency (sometimes referred to as the "visual grasp"). Such disinhibition is deemed to release approach-related processes in occipital-parietal regions (Butters et al., 1988; Kwon and Heilman, 1991) which in the present case could have invoked a leftward bisection bias. It is possible that the lines were less effective than the other stimuli in eliciting a right hemisphere visual grasp, which in turn allowed the inherently right (and by association distal) attentional bias of the left hemisphere to dominate that of the injured right hemisphere. The influence of the left hemisphere may have been further strengthened by the fact that that the line stimuli probably placed lighter demands on right hemisphere processes concerned with visuo-spatial search and scanning (see Corbetta & Shulman, 2002). It may also be relevant that, while the lines were most likely coded as a single perceptual element, the other stimuli were most likely treated as containing multiple perceptual items. The switch from single to multiple item displays elicited the same horizontal reversal in patient J.R., who was also left-handed and showed a very similar lesion distribution (Humphreys & Riddoch, 1995). The authors attributed his left and right neglect to damaged stimulus encoding processes in right fronto-parietal and left occipital-parietal regions, respectively.

These links between left and proximal space on one hand, and right and distal space on the other, support the idea that representations of left and proximal space are mapped to one part of the brain (and accordingly neglected together), while representations of right and distal space are mapped to another (and likewise neglected together). To this end, we note that C.P.'s neglect of leftward and proximal space during line bisection has been reported in other individuals with bilateral brain injury (e.g., Mennemeier, Wertman, & Heilman, 1992), and contrasts with the rightward and distal neglect shown by those with different patterns of injury (e.g., Coslett et al., 1993). C.P.'s bisection error is also consistent with the tendency of young, neurologically healthy adults to bisect lines in a leftward direction when placed relatively proximally, and in a more rightward direction when placed more distally (Varnava et al., 2002). According to Previc (1990), these spatial associations map to different cerebral hemispheres, such that the right hemisphere is specialized for both left hemi-space and near-vision functions (e.g., limb co-ordination, visual-vestibular integration, global perceptual analysis) while the left hemisphere is specialized for both right hemi-space and far-vision functions (e.g., recognition, local perceptual analysis). The behavior of patient C.P. provides particularly strong support for these associations because his neglect afflicts all four sectors of horizontal and radial space (i.e., left/proximal *and* right/distal). This contrasts with the "two sector" biases reported in all others who show co-incident horizontal and radial neglect (i.e., left/proximal *or* right/distal). These cases constitute a weaker form of evidence because they are also consistent with the contrary view that, in any given individual, only one region of horizontal space can be coupled with one region of radial space.

To conclude, we report that the direction of bisection error in horizontal and radial neglect can be co-reversed following a change in stimulus configuration. This co-reversal provides new evidence for the idea that common mechanisms guide the deployment of attention across orthogonal spatial planes, and endorses the view that left/proximal space is coded separately to right/distal (Previc, 1990). Given that patient C.P. shows a predominantly right neglect, is left-handed, and has bilateral brain damage, studies should now seek to estimate the incidence of co-reversals in those with more common sub-types of neglect.

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