

## NOTE

# WITHIN- AND BETWEEN-TASK DISSOCIATIONS IN VISUO-SPATIAL NEGLECT: A CASE STUDY

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## ABSTRACT

We describe a patient, J.B., who suffered an infarction of the right internal capsule and thalamus. There was a pronounced left hemiplegia but no visual field deficit. Investigated at four months and four years post-stroke, there were no signs of left visuo-spatial neglect other than a severe impairment of line bisection. The results on a test of perceptual judgement of the left and right extents of pretransected lines showed mild neglect of the left. The magnitude of this deficit did not predict quantitatively the severity of the patient's rightward deviation on a manual bisection task. Additional data are also reported on perceptual judgements and (manual) bisections of radially-oriented lines.

## INTRODUCTION

Horizontal line bisection and cancellation tasks are widely regarded as sensitive, quantitative tests of left visuo-spatial neglect after right-hemisphere lesion (Heilman, Watson and Valenstein, 1993). Nonetheless, we have previously reported a classic (and reliable) double-dissociation between the two tasks. Two (male) patients (HD and WS) had suffered right temporo-parietal infarcts (with associated left hemianopia and hemiplegia); yet one patient (HD) was severely impaired on cancellation but within normal limits on bisection, while the other patient (WS) showed severe (left) neglect on bisection but scored within normal limits on cancellation. Time post-onset was 6 months for HD and 3 months for WS (Halligan and Marshall, 1992).

Two further papers have reported positive but non-significant correlations between bisection (in)accuracy and cancellation omissions in larger groups of patients with right-hemisphere lesions. The twenty-one stroke patients with hemineglect studied by Binder, Marshall, Lazar et al. (1992) gave a correlation of  $+0.39$  between the two tasks; the ten stroke patients studied by Halligan and Marshall (1993) gave a correlation of  $+0.43$ . We accordingly concluded that visual search tasks are "measuring aspects of neglect that are distinct from those assessed by line bisection" (Halligan and Marshall, 1993). A more extreme conclusion might be that the theoretical construct of left visuo-spatial neglect (as currently diagnosed in peripersonal space) is "a meaningless entity" (Halligan and Marshall, 1992). Polemic aside, however, none of these papers makes any serious *functional* attempt to explain how such dissociations could arise; the move to a neuro-anatomical explanation is decidedly premature (Binder, Marshall, Lazar et al., 1992) in the absence of a coherent information-processing account on *how* such tasks as cancellation and line bisection are actually performed. In the current paper, we report a new case of right-hemisphere stroke (J.B.) who showed normal performance on cancellation tasks, but severe and persisting 'left neglect' on a conventional test of horizontal line bisection. We then explore some variant tasks that involve

estimation (either purely perceptual or perceptuo-motor) of the mid-point of lines. The results on these tasks constrain the interpretation of J.B.'s bisection impairment.

#### CASE HISTORY

J.B. is a right-handed man who suffered a right-hemisphere stroke on 25.2.1990 at the age of 61. The main neurological symptoms were a severe left hemiparesis (on the Motricity Index he scored 45% for the left arm and 47% for the left leg) and left-sided sensory loss. There was no visual field deficit, although left extinction was found in both the visual and tactile modalities. There were also clinical indications of left neglect. Visual acuity (glasses corrected) was 6/12 in the right eye and 6/9 in the left eye. Full ocular movements were possible in all directions, although visual pursuit was somewhat jerky, especially in the right-to-left direction. Stereopsis was good and the presence of full visual fields was independently confirmed on 5.5.1990. CT-scan (25.2.1990) showed low attenuation in the posterior limb of the right internal capsule and thalamic regions. The scan was consistent with infarction, with no evidence of either haemorrhage or mass effect.

J.B. was first seen by us (at Rivermead) on 19.6.1990. At this time (fifteen weeks post-stroke), his BIT (Behavioural Inattention Test) score (Halligan, Cockburn and Wilson, 1991) was 133/146, an overall performance that is within normal limits. On the individual subtests of the BIT, his scores were within normal limits on each of the three cancellation tasks (line crossing, 36/36; letter cancellation, 35/40; and star cancellation, 52/54). On copying geometric figures and on representation drawing, he was at ceiling. The only subtest on which there was impairment was line bisection (4/9); the three horizontal lines (staggered from right to left across the page) each 205 mm long were respectively transected at +25, +15 mm, and +22 mm to the right of the true midpoint. From this time until our most recent investigations in 1994, there has been little or no change in J.B.'s neurological status and no further neurological episodes have taken place. We have accordingly explored further the nature of J.B.'s impairment on line bisection.

#### EXPERIMENT 1

The purpose of this investigation was to ascertain whether J.B. shows the typical linear relationship between line length and transection displacement on a line bisection task (Halligan and Marshall, 1993).

##### *Materials and Method*

J.B. bisected 110 horizontal lines, with the right hand commencing each trial in its normal position on the right side. Eleven line lengths were employed, from 1 in. (25 mm) to 11 in. (279 mm) in steps of 1 in. These black lines, each approximately 1 mm wide, were individually drawn on sheets of white A4 paper (298 × 208 mm). Each line was centred on the page, both horizontally and vertically. Order of presentation of line length was pseudorandom; one block of 11 lines, one line at each length, was presented and then rerandomized and iterated until 110 trials (10 blocks × 11 lengths per block) were completed. Each stimulus sheet was positioned on the desk such that the lateral midpoint lay in the sagittal midplane of the patient's trunk and head. Viewing distance was approximately 450 mm. J.B. made his transections with a fine pen held in the preferred (right) hand.

The task was performed twice, once on 19.6.1990 (approximately four months post-stroke) and once on 25.5.1994 (over four years post-stroke).

##### *Results*

The distance between each transection and true centre was measured to the closest millimetre and expressed as minus (−) for leftward and plus (+) for rightward displacements. The results (mean displacement and standard deviation per line length) from the two testing

TABLE 1  
*Mean Displacements for Line Bisection by J.B. in the Two Testing Sessions*

Line length	Signed displacement 1 (S.D.)	Signed displacement 2 (S.D.)
279 mm (11")	+ 31.4 (7.6)	+ 26.0 (4.2)
254 mm (10")	+ 26.5 (8.7)	+ 21.7 (3.0)
228 mm (9")	+ 26.3 (5.5)	+ 20.0 (3.2)
203 mm (8")	+ 18.5 (5.1)	+ 17.1 (5.4)
178 mm (7")	+ 16.0 (4.6)	+ 14.8 (4.1)
152 mm (6")	+ 13.6 (3.4)	+ 13.5 (3.4)
127 mm (5")	+ 13.2 (2.2)	+ 13.3 (2.2)
102 mm (4")	+ 8.8 (3.5)	+ 9.2 (2.0)
77 mm (3")	+ 6.3 (2.0)	+ 7.7 (1.8)
51 mm (2")	+ 3.4 (1.8)	+ 3.7 (0.9)
25 mm (1")	+ 1.6 (0.9)	+ 0.9 (0.6)

sessions are shown in Table I. For session one, the linear regression Transection Displacement (TD) =  $-2.611 + 0.1160 \times \text{line length}$  accounts for 97.6% of the variance. The comparable equation for the Standard Deviation (SD) is  $-0.102 + 0.0277 \times \text{line length}$ , accounting for 88.9% of the variance. For session two, the equations are: TD =  $-0.311 + 0.090 \times \text{line length}$ , accounting for 98.1% of the variance; and SD =  $+0.654 + 0.014 \times \text{line length}$ , accounting for 65.5% of the variance.

#### *First Preliminary Discussion*

All regressions are significantly linear. On both testing sessions, J.B.'s transection displacements are grossly outside normal limits (Halligan and Marshall, 1993) and there is no evidence of significant recovery over the four years that separates the two sessions. On line bisection, then, J.B. shows severe, and reliable, left neglect that is quantitatively and qualitatively comparable to that reported in other patients after right-hemisphere damage (Halligan and Marshall, 1933). J.B. is unusual, however, in three respects: He does *not* have a visual field deficit; gross neglect on bisection has persisted for over four years; and he shows no deficit on cancellation tasks. On first testing (19.6.1990), he made only two omissions on star cancellation; on second testing (25.5.1994), he performed the task twice, once making two omissions and once making no omission. Two omissions are within normal limits. Similarly, J.B.'s letter cancellation is within normal limits; control subjects make up to eight omissions (Halligan, Cockburn and Wilson, 1991); J.B. made five.

Just *how* unusual a patient J.B. may be is debatable. WS (reported in Halligan and Marshall, 1992) showed a comparable dissociation between bisection and cancellation (after temporo-parietal damage), as did patients 1 and 3 in the study by Binder, Marshall, Lazar et al. (1992). The latter two patients, who were tested one and sixteen days post-stroke, respectively, were similar to J.B., in that they did not have a visual field deficit; they differed from J.B. in that their lesion sites were parietal and parieto-frontal, respectively. Also relevant is the case of Ferro and Kertesz (1984). This man, like J.B., had a lesion that involved primarily the right posterior internal capsule. There was both left hemiparesis and left homonymous hemianopia. Two weeks post-stroke, the patient showed neglect on both cancellation and line bisection; but three months after onset, cancellation was normal while bisection still produced transections that were significantly to the right of centre. The existence of these patients makes one suspect that there are many more who manifest a similar dissociation on (so-called) tests of 'visuo-spatial neglect'. The crucial point for the moment, however, is to elucidate the nature of J.B.'s bisection impairment.

#### EXPERIMENT 2

Poppelreuter (1917/1990) was the first to suggest that impairments of line bisection could be due to either perceptual or motor factors: "perceptual judgement" might be impaired, or

there might be a "visual apraxia" in which error arises from "an impairment of motor execution". Until recently, however, there have been few attempts to explore the consequences of this distinction with specific reference to the bisection task (Rosenberger, 1974; Halligan and Marshall, 1989a, 1989b; Marshall and Halligan, 1989; Bisiach, Beminiani, Berti et al., 1990; Tegnér and Levander, 1991; Binder, Marshall, Lazar et al., 1992; Milner, Harvey, Roberts et al., 1993). Accordingly, we next inquire whether J.B.'s performance on a purely judgemental (perceptual) task (similar to that used by Milner, Harvey, Roberts et al., 1993) predicts the magnitude of his transection errors in a standard manual bisection task. The data were collected four years post-stroke.

### Materials and Method

Pretransected lines of 180 mm were prepared (centred, as before, on individual sheets of A4 paper). In each block of 7 lines, the transections (a 1 mm by 4 mm vertical line) were placed at -15, -10, -5, 0, +5, +10, and +15 mm from the veridical midpoint. Each stimulus was placed on the desk (as in Experiment 1), and J.B. was requested to state (verbally) whether the line was correctly bisected, and, if not, which end (left or right of the transection) was the longer. Individual stimuli were presented in blocks of seven lines which were re-randomized after each block until a total of 140 judgements had been obtained (7 lines  $\times$  20 blocks).

Unmarked lines of 180 mm were also presented for (manual) bisection in two conditions: the standard condition in which the right hand commenced each bisection from the right side of the line; a "crossed" condition in which, prior to each bisection, J.B. placed his right hand at the left (and slightly below) each stimulus line (Halligan, Manning and Marshall, 1991; Halligan, Donegan and Marshall, 1992). Six blocks of 10 trials each were run: three blocks with "right start" and three blocks with "left start". For the third "left start" block, J.B. in addition to placing his hand at the left of the line, also marked the left end thereof with a small cross prior to commencing his bisection. Results were scored as in Experiment 1.

### Results

The results of the perceptual judgement task are shown in Figure 1. It can be seen that a highly lawful psychophysical function is obtained. The distribution of 'equality' judgements has been shifted slightly rightward of veridical zero; the modal estimate of equality is found at +5, and even at transections of +15, J.B. still judges 25% of the lines to be of equal length. Our own unpublished control data, and those of Milner, Harvey, Roberts et al. (1993) indicate that normal subjects are essentially at ceiling with discrepancies of  $\pm 5$  mm; that is, their comparative length judgements are veridical within these limits. Thus J.B. shows a small measure of purely 'perceptual' (left) neglect on this task. J.B.'s "indifference zone" (Marshall and Halligan, 1990), within which objectively unequal lines are judged equal, is both wider than that of normal subjects and skewed rightward from objective equality; the mode of the distribution is at +5 (not zero).

The results of the manual bisection task are shown in Table II. All blocks show transections that are well to the right of those of control subjects, where mean performance with right start is *circa* +1.6 and with left start *circa* -2.5 mm (Irving-Bell, 1993). The motoric "indifference zone" within which he makes his manual transection (under the instruction that they should bisect the line) is now further skewed to the right of true centre. J.B.'s performance is reasonably consistent across the three replications and there is no

TABLE II  
*Magnitudes of Signed Displacements in mm (+S.D.) for Line Bisection*

Line length (180 mm)	Left start	Right start
Block 1	+12.7 (3.2)	+11.7 (4.3)
Block 2	+15.2 (4.2)	+16.9 (3.3)
Block 3	+10.0 (5.4)	+11.8 (3.8)

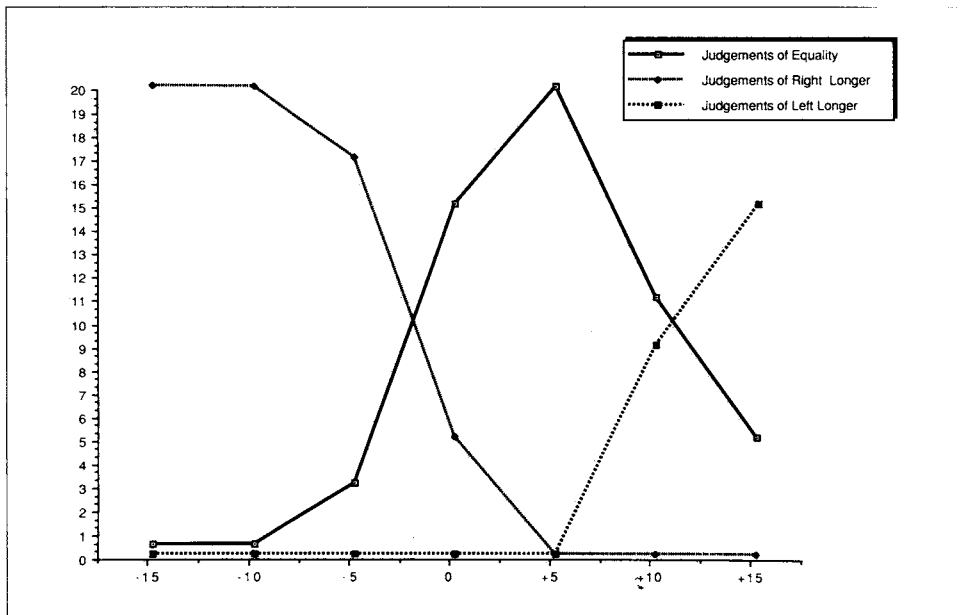


Fig. 1 – Judgements of equality and inequality for the two segments of a pretransected horizontal line.

significant effect of starting position; the effects of starting position are known to be extremely variable from patient to patient with neglect (Halligan and Marshall, 1994).

### Second Preliminary Discussion

It is possible to calculate the results of the judgement tasks *as if* they were manual bisections. We take each judgement of equality and regard it as a bisection: the set is  $-5 \times 3, 0 \times 15, +5 \times 20, +10 \times 11$ , and  $+15 \times 5$ . The mean and standard deviation of this set is:  $+5.0$  (5.2). This measure contrasts with an *obtained* mean and standard deviation of  $+13.5$  (4.5), calculated from the three sets of right start bisections, and a similar figure of  $+12.6$  (4.7), calculated from the three sets of left start bisections. In Figure 2, we show histograms of the relevant comparison. The equality judgements (from Figure 1) are reproduced with the actual bisections (made in the right start condition); these bisections ( $n=30$ ) have been grouped into the displacement categories ( $\pm 2$  mm) employed in the judgement task. The left start conditions (Table II) are indistinguishable from the right start conditions.

It can readily be seen that J.B.'s manual bisections are significantly to the right of the performance that had been predicted from his bisection judgements. One component of J.B.'s 'neglect' on line bisection may thus be 'motoric' (manual). That motor (or pre-motor) component cannot, however, be described straightforwardly as a 'directional' *hypometria*; the same (positive) displacement is obtained with left and with right start. One would have to say that J.B. showed right-to-left directional hypometria but left-to-right directional hypermetria. Interpreted vectorially (Kinsbourne, 1993; Burnett-Stuart, Halligan and Marshall, 1991), it is *as if* J.B. was, on a right-to-left trajectory, moving *into* a prevailing East wind, but being 'blown along' by that wind when moving on a left-to-right trajectory.

### EXPERIMENT 3

Although not directly relevant to the previous studies of *lateral* extent estimation, we have also explored the bisection and judgement of radial lines in J.B. (Four years post-

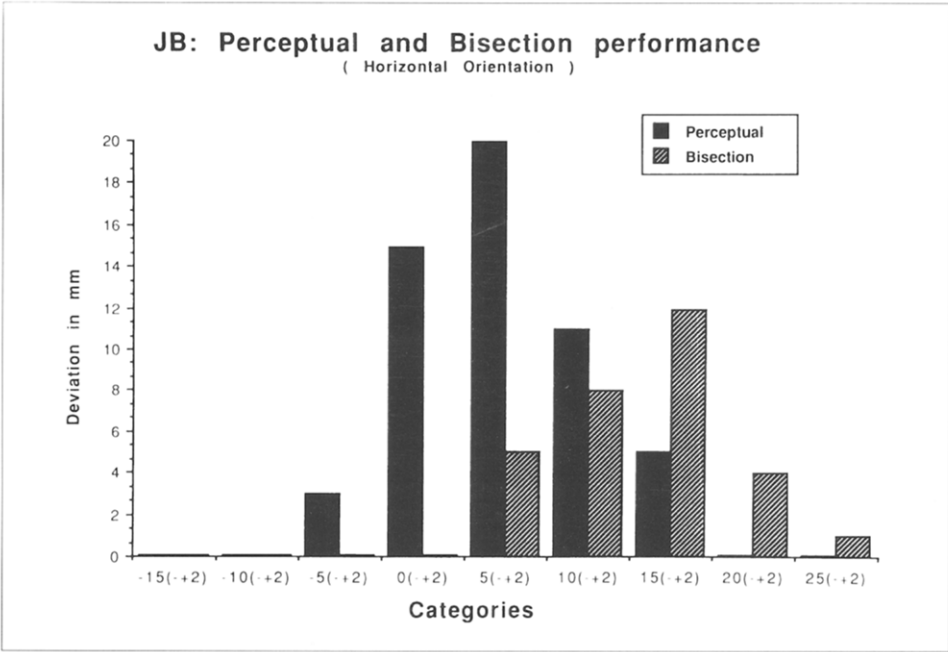


Fig. 2 – Direct comparison of perceptual judgements and bisection performance for horizontal lines.

stroke). Experiment 2 was replicated with the sole difference that the lines were now displayed radially on the desk top. The results for the judgement task with pretransected lines are shown in Figure 3.

Performance is fairly good. The mode for judgements of equality does indeed fall at 0, although there are substantial numbers of equality judgements at + 5 mm (30%) and – 5 mm (85%). Outside these limits, judgements are accurate at + 10 mm, although 25% of the lines transected at – 10 mm are still judged equal. The mean and standard deviation of the set of lines judged equal is – 2.02 mm (4.4). As before, we can ask whether this calculation predicts the accuracy of J.B.’s performance on (manual ballistic) line bisection with radial presentation. This latter task was performed twice (2 blocks of 10 lines of 180 mm) with each of two starting positions: the hand placed at the bottom (near) end of the stimulus page versus the hand placed at the top (far) end of the stimulus page. The results, scored as before, with + indicating transections too far from the body and – indicating transections too close to the body, are shown in Table III.

In Figure 4, we display histograms of the equality judgements (shown in Figure 3) with the actual bisection (made in both top and bottom start conditions). Again, these bisections (n=20 for each starting position) are grouped into the displacement categories ( $\pm 2$  mm) used in the perceptual judgement task. With ‘bottom start’, there is a good correspondence between the results of the perceptual judgement task and the results of the manual bisection

TABLE III  
*Magnitudes of Signed Displacements in mm (+ S.D.) for Line Bisection*

Line length (180 mm)	Top start	Bottom start
Block 1	– 8.7 (2.8)	– 0.6 (3.7)
Block 2	– 8.3 (3.7)	– 1.4 (3.9)
Mean of 1 and 2	– 8.5 (3.2)	– 1.0 (3.7)

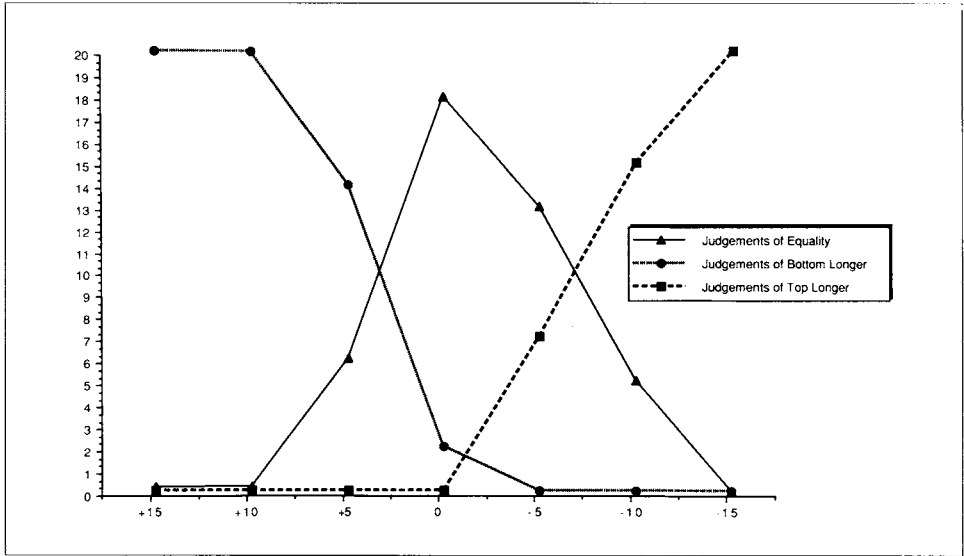


Fig. 3 – Judgements of equality and inequality for the two segments of a pretransected radial line.

task. The mean displacement on the former task (calculated as before from the judgements of equality) is  $-2.02$  mm; the mean of the bisection displacements is  $-1.0$  mm. Although J.B.'s manual bisections are objectively very accurate in this condition, they may nonetheless be 'abnormal'; normal subjects show a strong tendency to bisect radial lines significantly too far from the body (Halligan and Marshall, 1993; Jeerakathil and Kirk, 1994). With top

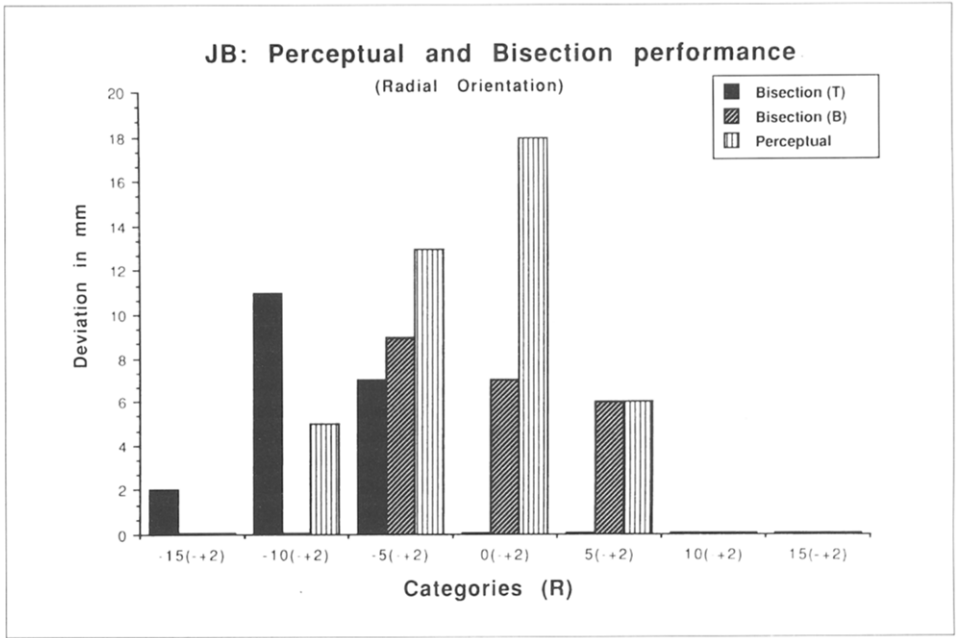


Fig. 4 – Direct comparison of perceptual judgements and bisection performance for radial lines: T=Top start; B=Bottom start.

start, by contrast, J.B.'s transection displacements are made too close to the body ( $-8.5$  mm).

If one takes the judgement task as a 'pure' measure of perceptual performance, J.B.'s actual bisections reveal no 'motor' impairment when he commences the task from 'nearer' space. The results from the condition with top (far) start could be described as directional hypermetria toward the body. Again, then, the relationship between the 'perceptual' and the 'motor' components of line bisection is susceptible to modification by the particular nature of the task-conditions.

## GENERAL DISCUSSION

Although rightward displacement of 'bisections' is an old observation in the study of left neglect, Bisiach, Bulgarelli, Sterzi et al. (1983) were the first to see any serious theoretical content in the phenomenon. They introduced the concept of the *represented* line, which they defined as double the extent to the right of the patient's transections. The *represented line* is thus (by definition) correctly bisected, but since the objective lines must have been (variably) 'amputated' on the left in order to yield their (internal) representations, the patient's transections are (objectively) displaced to the right of true centre.

This line of argument proved remarkably fertile, giving rise to a veritable flood of theoretically-driven research on line bisection in patients with right hemisphere lesions. The repeated demonstration that transection displacement was proportional to (stimulus) line length (Bisiach, Bulgarelli, Sterzi et al., 1983; Riddoch and Humphreys, 1983; Halligan and Marshall, 1988; Nichelli, Rinaldi and Cubelli, 1989; Chatterjee, Mennemeier and Heilman, 1994) drove home the realization that (in some sense) the entire line must have been 'seen' at some early processing stage (Bruyer, 1984; Marshall and Halligan, 1990). We accordingly suggested that one could interpret the results from patients with neglect as reflecting an increased Weber fraction for length discrimination; the patients, we conjectured (Marshall and Halligan, 1990), approached their pathologically increased 'indifference zones' from the right and made their actual (motoric) transections at the point where the initial judgement of equality was made.

As they were stated at the time, both the accounts of Bisiach, Bulgarelli, Sterzi et al. (1983) and of Marshall and Halligan (1990) assumed that the primary deficit was perceptual. But the notion of a "representational scotoma" (Bisiach, Bulgarelli, Sterzi et al., 1983) does not fit comfortably with the idea that the *perceptual* representation may be relatively intact (at one level at least). Likewise, the account given in Marshall and Halligan (1990) would not have predicted the major discrepancy found here between the perceptual judgement task and the manual bisection task. By contrast, the notion that errors in manual (ballistic) bisection (with right start) might *motorically* 'undershoot' by an extent proportional to line length does seem consistent with (relatively) intact *perception* of stimulus length. Thus 'directional hypometria' may be an accurate *description* of the results of the current Experiment 2 *with right start*. Problems then arise with the observation that the same quantitative *rightward* displacement is found with *left start*. At this point, one could invoke the converse notion of directional hypermetria (in left-to-right movements) in order to 'save the appearances' (but, again, only descriptively).

By contrast, when pretransected lines are presented, the perceptual system may explicitly compare the *two* lines (to the left and right respectively of the transection mark). 'Attention' is divided between *two* objects that have a *physically*-marked boundary. There is, in short, an important task-difference over and above the obvious difference between tasks with and without *manual* responding.

Traditional (manual) line bisection is likewise cognitively very different from cancellation tasks (on which J.B. is unimpaired). In cancellation tasks, there are *physical* targets to be detected (and, provided the cancellation response hits the target, it does not matter *where* it does so). In line bisection, there is no physical *target* present at the midpoint of the line to distinguish the point from any other point on the line; the midpoint has to be *computed* on the basis of the (physically-detectable) endpoints of the stimulus line (and the extent between them). And, of course, if J.B. is given lines of 180 mm each one pre-transected at a different point (between  $-15$  mm to  $+15$  mm from true centre) and asked to cancel the transection



mark; he has no difficulty in so doing. To be sure, both cancellation and line bisection involve the spatial localization of visible stimuli; but only the latter task demands, in addition, the computation of the position of a target that is not physically given.

The endpoints of a line are *terminators* in the sense of Julesz (1984); they can be detected by hypercomplex (end stopped) visual cortical neurons and are no doubt involved in length analysis (Dobbins, Zucker and Cynader, 1989). There may be cells (and there must be circuits) that respond to line length (Hubel and Wiesel, 1988); as Nakayama and Roberts (1972) note "Hypercomplex cells by virtue of having contour-sensitive inhibitory flanks are length specific." But endpoint detection and length estimation are not the same thing. Still less are endpoint detection and half-length (mid-point) estimation the same thing. There cannot be neuronal 'detectors' for half-length, for the simple reason that there is (literally) nothing to detect, other than the line per se, until after the experimenter or the subject has transected the line. Half-length is a computed function, and one reason why we do not understand line bisection impairment in neglect is that there are no models that explain *how* normal subjects perform this task.

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#### REFERENCES

- BINDER, J., MARSHALL, R., LAZAR, R., BENJAMIN, J., and MOHR, J.P. Distinct syndromes of hemineglect. *Archives of Neurology*, 49: 1187-1194, 1992.
- BISIACH, E., BULGARELLI, C., STERZI, R., and VALLAR, G. Line bisection and cognitive plasticity of unilateral neglect of space. *Brain and Cognition*, 2: 32-38, 1983.
- BISIACH, E., BULGARELLI, G., BERTI, A., and RUSCONI, M.L. Perceptual and premotor factors in unilateral neglect. *Neurology*, 40: 1278-1281, 1990.
- BRUYER, R. Neglects in hemineglect: A comment on the study of Bisiach et al. (1983). *Brain and Cognition*, 3: 231-234, 1984.
- BURNETT-STUART, G., HALLIGAN, P.W., and MARSHALL, J.C. A Newtonian model of perceptual distortion in visuo-spatial neglect. *NeuroReport*, 2: 255-257, 1991.
- CHATTERJEE, A., MENNEMEIER, M., and HEILMAN, K.M. The psychophysical power law and unilateral spatial neglect. *Brain and Cognition*, 252: 92-107, 1994.
- DOBBINS, A., ZUCKER, S.W., and CYNADER, M.S. Endstopping and curvature. *Vision Research*, 29: 1371-1387, 1989.
- FERRO, J.M., and KERTESZ, A. Posterior internal capsule infarction associated with neglect. *Archives of Neurology*, 41: 422-424, 1984.
- HALLIGAN, P.W., COCKBURN, J., and WILSON, B. The behavioural assessment of visual neglect. *Neuropsychological Rehabilitation*, 1: 5-32, 1991.
- HALLIGAN, P.W., DONEGAN, C.A., and MARSHALL, J.C. When is a cue not a cue? On the intractability of visuo-spatial neglect. *Neuropsychological Rehabilitation*, 2: 283-293, 1992.
- HALLIGAN, P.W., MANNING, L., and MARSHALL, J.C. Hemispheric activation vs spatio-motor cueing in visual neglect: A case study. *Neuropsychologia*, 29: 165-175, 1991.
- HALLIGAN, P.W., and MARSHALL, J.C. How long is a piece of string? A study of line bisection in a case of visual neglect. *Cortex*, 24: 321-328, 1988.
- HALLIGAN, P.W., and MARSHALL, J.C. Two techniques for the assessment of line bisection in visuo-spatial neglect: A single case study. *Journal of Neurology, Neurosurgery and Psychiatry*, 52: 1300-1302, 1989a.
- HALLIGAN, P.W., and MARSHALL, J.C. Perceptual cueing and perceptuo-motor compatibility in visuo-spatial neglect: A single-case study. *Cognitive Neuropsychology*, 6: 423-435, 1989b.
- HALLIGAN, P.W., and MARSHALL, J.C. Left visuo-spatial neglect: A meaningless entity? *Cortex*, 28: 525-535, 1992.
- HALLIGAN, P.W., and MARSHALL, J.C. The bisection of horizontal and radial lines: A case study of normal controls and ten patients with left visuo-spatial neglect. *International Journal of Neuroscience*, 70: 149-169, 1993.
- HALLIGAN, P.W., and MARSHALL, J.C. Right-sided cueing can ameliorate left neglect. *Neuropsychological Rehabilitation*, 4: 63-73, 1994.
- HEILMAN, K.M., WATSON, R.T., and VALENSTEIN, E. Neglect and related disorders. In K.M. Heilman:

- and E. Valenstein (Eds.), *Clinical Neuropsychology*. New York: Oxford University Press, 1993.
- HUBEL, D.H., and WIESEL, T.N. Receptive fields and functional architecture of monkey striate cortex. *Journal of Physiology, London*, 195: 215-243, 1968.
- IRVING-BELL, L. Neurophysiology and neuropsychology of visuo-spatial neglect: Analysis of spatial cues in normal control subjects and patients with neglect. *Honours Project*, University of Oxford, 1993.
- JEERAKATHIL, T.J., and KIRK, A. A representational vertical bias. *Neurology*, 44: 703-706, 1994.
- JULESZ, B. Toward an axiomatic theory of preattentive vision. In G.M. Edelman, W.E. Gall, and W.M. Cohen (Eds.), *Dynamic Aspects of Neocortical Function*. New York: Wiley, 1984.
- KINSBOURNE, M. Orientational bias model of unilateral neglect: Evidence from attentional gradients within hemispace. In I.H. Robertson and J.C. Marshall (Eds.), *Unilateral Neglect: Clinical and Experimental Studies*. Hove (UK): Lawrence Erlbaum Associates, 1993.
- MARSHALL, J.C., and HALLIGAN, P.W. When right goes left: An investigation of line bisection in a case of visual neglect. *Cortex*, 25: 503-515, 1989.
- MARSHALL, J.C., and HALLIGAN, P.W. Line bisection in a case of visual neglect: Psychophysical studies with implications for theory. *Cognitive Neuropsychology*, 7: 107-130, 1990.
- MILNER, A.D., HARVEY, M., ROBERTS, R.C., and FORSTER, S.V. Line bisection errors in visual neglect: Misguided action or size distortion? *Neuropsychologia*, 3: 39-49, 1993.
- NAKAYAMA, K., and ROBERTS, D.J. Line length detectors in the human visual system: Evidence from selective adaptation. *Vision Research*, 12: 1709-1713, 1972.
- NICHELLI, P., RINALDI, M., and CUBELLI, R. Selective spatial attention and length representation in normal subjects and in patients with unilateral spatial neglect. *Brain and Cognition*, 9: 57-70, 1989.
- POPPELREUTER, W. *Disturbances of Lower and Higher Visual Capacities Caused by Occipital Damage* (J. Zihl, Trans.). Oxford: Clarendon Press, 1990.
- RIDDOCH, M.J., and HUMPHREYS, G.W. The effect of cueing on unilateral neglect. *Neuropsychologia*, 21: 589-599, 1983.
- ROSENBERGER, P.B. Discriminative aspects of visual hemi-inattention. *Neurology*, 24: 17-23, 1974.
- TEGNER, R., and LEVANDER, M. Through a looking glass: A new technique to demonstrate directional hyperkinesia in unilateral neglect. *Brain*, 114: 1943-1951, 1991.