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Hemispheric antagonism in visuo-spatial neglect: A case study

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Abstract

We report a case of severe visuo-spatial neglect consequent upon right-hemisphere stroke. At the time of testing, the patient had no visual field cut and no significant hemiparesis. Conventional testing on cancellation tasks with the right hand revealed reliable left neglect, but performance was significantly improved when the left hand was used. Investigations of (manual) line bisection showed normal performance with the right hand but right neglect when the left hand was used. Right neglect was also observed on a purely perceptual version of the line bisection task. We argue that the attentional vectors of the cerebral hemispheres can be modulated by (perceptual) task-demands and by (motoric) response-demands. (*JINS*, 1996, 2, 412–418.)

Keywords: Visuo-spatial neglect, Cancellation and line bisection, Laterality of manual response

INTRODUCTION

In previous papers (Halligan & Marshall, 1989; Halligan et al., 1991b), we have emphasized the fact that the left visuo-spatial neglect shown by many patients with right temporo-parietal damage is crucially linked to the attentional capacity of the normal (undamaged) left hemisphere. The reason is simple: most patients with florid, persistent left neglect have widespread damage that results in left hemiplegia and left hemianopia. They are perforce tested with only the right hand, which is primarily under the control of the intact left hemisphere. Furthermore, visual stimuli with which they are presented (in free vision) will similarly be projected directly to the intact left hemisphere. It follows, then, that left neglect is (in part at least) a symptom-complex shown by a structurally intact left hemisphere when that hemisphere is no longer "balanced" by a (damaged) right hemisphere.

A plausible (and empirically well-supported) account of some basic aspects of left neglect is accordingly that of Kinsbourne (1993). Kinsbourne argued that, in normal subjects, the two cerebral hemispheres have opposing orientational tendencies to attend to contralateral space. Spatial neglect then occurs when a unilateral lesion provokes an imbalance in the direction of spontaneous attentional orientation; a system that is normally "in mutually inhibitory balance" becomes biased toward the ipsilesional spatial domain subserved (preferentially) by the intact hemisphere (Kinsbourne, 1974). In the normal brain, the (focal) contralateral bias of the left hemisphere is somewhat stronger than that of the (more panoramic) right (Halligan & Marshall, 1994a, 1994b). Hence, right hemisphere damage "leaves the strong rightward orienting tendency" of the left hemisphere "unopposed" (Reuter-Lorenz et al., 1990) and thus gives rise to the well-known asymmetry in the incidence and severity of left neglect after right brain damage versus right neglect after left brain damage.

In this model, left neglect is not *caused* by left hemiparesis and/or left hemianopia (the account does not "reduce" neglect to visual or motor impairment); but nonetheless the expression of a rightwards attentional bias (by the left hemisphere) is made maximally manifest by the co-occurrence of left hemiparesis, left hemianopia, and the use of the right hand. Not only is the opposing bias of the right hemisphere reduced by damage, but that hemisphere is (often) also cut off from (direct) sensory and visual input and from manual expression.

It is consistent with this line of argument that the overt severity of left neglect can (often) be reduced by use of the left hand in those patients who are without contralesional

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paresis (Halligan et al., 1991b). This lateralized response mode presumably boosts the level of activation of the damaged right hemisphere (and hence reestablishes a more normal balance between the hemispheres), although it is not always easy to disentangle the effects of direct hemispheric activation and left spatio-motor cueing (Halligan et al., 1991b; Robertson & North, 1992). Studies of patients with callosal lesions have shown left neglect on line bisection when using the right hand and right neglect when using the left hand (Goldenberg, 1986; Heilman et al., 1984). These results are also in keeping with Kinsbourne's model, whereby each disconnected hemisphere attends to contralateral space.

Issues that remain open are these: What pattern of attentional performance would one expect from a damaged right hemisphere if that hemisphere could express itself directly (i.e., if it were not inhibited by the intact left)? Could the attentional bias of the (damaged) right hemisphere interact with that of the (structurally intact) left if, contrary to the "typical" case of left neglect, right hemisphere processes made a significant contribution to performance on some tasks even when the right hand was employed?

In the above circumstances, one might derive the following (initially counterintuitive and "paradoxical") predictions. First, if the intrinsic performance of a damaged right hemisphere *can* be elicited, the leftward attentional bias of that hemisphere should result in *right* neglect. Second, if the leftward bias of the (damaged) right hemisphere can be communicated to the intact left hemisphere, the left neglect characteristic of performance with the right hand (left hemisphere) should be attenuated on some tasks. As Reuter-Lorenz et al. (1990) argued, the way in which different cognitive tasks modulate attentional orienting "may depend in part on the extent to which particular regions within a hemisphere become activated during processing." A very similar account has been offered by Cubelli et al. (1991) for paradoxical neglect after unilateral left hemisphere lesion; their patient had left neglect dyslexia, but right neglect on cancellation tasks performed with the left hand.

If these conjectures are to find empirical support, they will presumably do so in patients with right hemisphere damage who have neither significant hemiparesis nor hemianopia. In such a patient, visual stimuli can project directly to the right hemisphere and manual response can likewise be programmed from it. Furthermore, selective communication between frontal (motor) cortices and between posterior (visual) cortices may be possible. We now report a series of relevant experiments on a patient who meets the requisite criteria for testing our hypotheses.

CASE REPORT

R.H. is a 61-year-old man with a history of elevated blood pressure. He is fully right-handed with a Laterality Quotient (LQ) of + 100 (Oldfield, 1971). R.H. was admitted to hospital on October 23, 1991 with weakness and numbness in his left arm. On examination, he appeared to have a left homonymous hemianopia with left inattention. Fundi showed silver wiring but no haemorrhages, exudates, or papilloedema. There was mild weakness of the left side (grade 4/5 in all groups) with loss of joint position sense distally and blunting of light touch sensation. Reflexes on the left side were brisk; the plantar reflex was equivocal. CT scan (October 24, 1991) showed an area of low attenuation in the right temporo-parietal region, consistent with a recent infarct in the territory of the right middle cerebral artery; there was no evidence of hemorrhage. MRI was performed on December 10, 1991. Consistent with the CT scan, the MRI (Fig. 1) showed infarction of right parietal cortex, extending to the superior temporal gyrus (and the underlying white matter). There were also multiple small white matter lesions in the right hemisphere and fewer small deep white matter lesions in the left hemisphere. These latter findings are consistent with the history of high blood pressure.

Neuropsychological testing was begun on November 8, 1991. At this time, we could detect no field cut, although there was left visual extinction on double simultaneous stimulation. There was no obvious weakness of the left arm or hand. Examined on the Behavioural Inattention Test (Halligan et al., 1991a) with the right hand, R.H. obtained a score of 74/146; the cutoff for normal performance is 130/146. Line cancellation was 27/36; letter cancellation, 13/40; star cancellation, 33/54; figure copying, 0/4; representational drawing, 1/3; and line bisection, 0/9. The only clinical peculiarity noted was that the patient usually looked sponta-

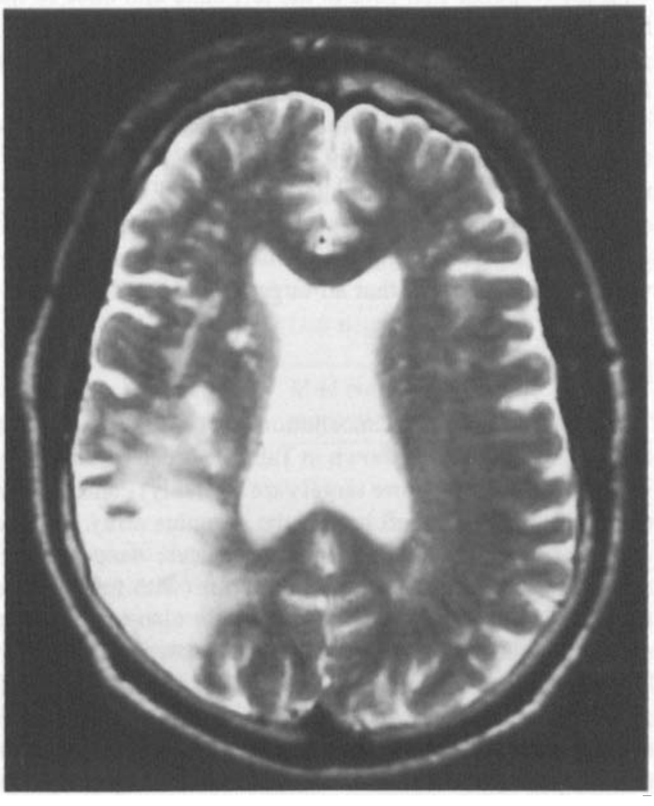

Fig. 1. The MRI shows infarction of right parietal cortex, extending to the superior temporal gyrus (and the underlying white matter).

neously to the left; this reversal of the typical direction of gaze after right hemisphere stroke persisted throughout the entire period of our investigations.

R.H. spoke slowly with slightly flattened intonation but normal syntax. There were no obvious word finding or comprehension difficulties and naming to confrontation (Newcombe et al., 1964) was within normal limits. General knowledge, vocabulary, and similarities (from the WAIS) were average (scaled scores were respectively 10, 9, and 9); digit span was 4 forwards and 2 backwards. Single-word reading was not investigated in detail, but R.H. was observed to make some errors characteristic of left neglect dyslexia (class → "glass"; place → "grace"; fireplace → "place"). In other instances, the error involved medial letters (grain → "green"; clock → "cook"; thing → "taking"; wash → "wish").

The observations were made over the period from November 8 to December 2, 1991.

EXPERIMENT 1

This experiment assesses the reliability of any deficit on cancellation tasks undertaken with the left and right hands.

Method

Two cancellation tasks from the Behavioural Inattention Test (BIT) were used (Halligan et al., 1991a). Line cancellation (in which all 36 stimuli are targets) are given twice, once with the response pen held in the left hand and once in the right; star cancellation (in which 54 small stars are the targets in the context of foils) was given six times, three with left hand and three with right hand responding. In all instances, the (A4) stimulus sheet was presented on the desk top and centered on the patient's midsagittal plane. R.H. commenced each trial with the hand of response (left or right) on its normal side (left and right, respectively). No time limit was imposed; the patient was instructed to put down the pen when he was satisfied that all targets had been cancelled.

Results

The results (number of cancellations on the left and right of the stimulus page) are shown in Table 1. It can be seen that, with the right hand, more targets are (reliably) cancelled on the right than on the left half of the stimulus array. On line cancellation, all targets in right space were cancelled; on the (more difficult) star cancellation test (with foils), some targets in right (ipsilesional) space were also missed. The cutoff for normal performance on star cancellation is two omissions in total (Halligan et al., 1991a). When the left hand was used, there was a reliable improvement in performance on both tests. On star cancellation, this improvement consisted in more correct cancellations in left space; omissions in right space were not significantly different from when the right hand was used. Although performance with the left hand is better than with the right, the total omissions are still outside normal limits. The overall conclusion is that left neglect with right hand responding has been transformed into mild generalized (visual) inattention with left hand responding.

Table 1. Correct responses on the left and right halves of two cancellation tasks performed with the left or right hand

Hand of response:	Left		Right	
Locus of cancelled items:	Left	Right	Left	Right
Correct responses				
Line cancellation	18/18	18/18	9/18	18/18
Star cancellation				
(1)	20/27	17/27	13/27	20/27
(2)	18/27	22/27	12/27	19/27
(3)	22/27	21/27	13/27	20/27

EXPERIMENT 2

We now assess the patient's performance on line bisection tasks, with motor response by either the left or right hand.

Method

Horizontal line bisection was performed with 10 lines (1 mm in width) that varied in length from 18 to 180 mm in steps of 18 mm. Each black line was presented individually and centered both horizontally and vertically on a sheet of white A4 paper (298 × 208 mm). Each stimulus sheet was placed on the desk top and was always centered on the midsagittal plane of the patient's head and trunk. All stimulus lines (for each of the four response conditions) were presented 10 times in each condition, with order of presentation pseudo-randomized across the lengths. R.H. bisected four sets of 100 lines (10 lengths × 10 trials) in the following four conditions: (1) with the right hand commencing each trial in right space; (2) with the right hand commencing each trial in left space; (3) with the left hand commencing each trial in left space; (4) with the left hand commencing each trial in right space. This design has been employed previously in Halligan et al. (1991b). The four sessions were spaced over 1 week. In two later sessions in 1991, the reliability of the two extreme conditions (left hand on the left and right hand on the right) was assessed with lines of 180 mm.

Results

Transection accuracy was measured to the nearest millimeter and expressed as positive (+) for rightward displacements and negative (−) for leftward displacements. The data are shown in Table 2. Descriptive statistical analyses are

Table 2. Mean transection displacements for the four experimental conditions (with standard deviations)

Line length (mm)	Right hand, right side	Right hand, left side	Left hand, left side	Left hand, right side
180	+1.8 (10.5)	−5.6 (10.0)	−16.6 (4.7)	−12.9 (9.1)
162	+1.1 (8.9)	−1.9 (7.3)	−13.4 (7.3)	−10.0 (6.9)
144	−2.6 (11.1)	−6.4 (7.1)	−16.9 (5.1)	−17.9 (9.0)
126	+1.1 (6.9)	−3.5 (7.3)	−9.1 (4.8)	−12.8 (6.9)
108	+0.6 (6.5)	−3.9 (4.9)	−12.1 (6.5)	−14.0 (10.2)
90	+0.5 (4.8)	−6.6 (4.9)	−8.0 (3.7)	−11.0 (5.7)
72	−2.9 (4.9)	−3.0 (3.6)	−7.2 (3.6)	−11.4 (5.5)
54	−1.4 (3.8)	−3.5 (3.4)	−8.4 (2.5)	−9.5 (4.7)
36	−1.5 (1.9)	−1.9 (3.0)	−5.6 (3.5)	−6.6 (2.9)
18	−1.1 (0.9)	−1.3 (1.1)	−4.3 (2.2)	−4.7 (2.6)
Replications (180)				
First	+0.8 (3.9)		−14.2 (4.1)	
Second	−3.3 (3.7)		−15.0 (3.9)	

shown in Table 3. These display the four regressions of transection displacements (with the proportion of variance accounted for), the four regressions of *SD* on line length (with the proportion of variance accounted for), the mean percentage displacement, and the coefficient of variation (CV) across all line lengths in the four conditions. It can be seen that the primary determinant of performance is the hand used. When the right hand bisects, performance is within normal limits (Halligan & Marshall, 1992; Irving-Bell, 1993), although the *direction* of transection displacement modulates toward the side of start for longer lines. When the left hand bisects, performance is reliably outside normal limits (Irving-Bell, 1993; Scarisbrick et al., 1987). Irrespective of side of start, transection displacements are to the left of center (= right neglect). This qualitative pattern persisted throughout all testing sessions.

EXPERIMENT 3

This experiment assesses line bisection without a manual response on the patient's part. We adopt the technique employed by Reuter-Lorenz and Posner (1990).

Method

A "directed-visual scan" task was used. Lines of 180 mm were presented (as in Experiment 2). In blocked trials, the experimenter moved a pen either from left to right along the line, or from right to left (with the starting position always at the end of the line). R.H. was instructed to follow the pen (visually) and say "stop" when the pen reached the midpoint. The pen was moved very slowly (about 1 mm per second). Ten trials were run with left start, and 10 with right start. The experiment was repeated three times (on separate days) in 1991 (sessions 1 to 3).

Results

Transection displacements were again scored to the nearest millimeter. The results are shown in Table 4. It can be seen that all mean displacements for the purely perceptual conditions are to the left of true center. All six mean displacements are considerably outside the normal limits of *ca.* 1% error reported by Reuter-Lorenz and Posner (1990). The qualitative pattern persisted throughout all testing sessions.

GENERAL DISCUSSION

The overall pattern of performance that demands explanation can be seen in the following summary of the data:

	Cancellation	Bisection
Right hand (= left hemisphere)	Left neglect	Normal
Left hand (= right hemisphere)	Mild nonlateralized inattention	Right neglect

There was, in short, a reliable *double*-dissociation of lateralized "neglect" *within* the same patient. To our knowledge, this phenomenon has never before been reported.

R.H.'s performance with the right hand is (relatively) unproblematic; this single-dissociation has been reported previously. Patient H.D., described in Halligan and Marshall (1992) had severe left neglect on cancellation, but performed within normal limits on line bisection. A similar dissociation was reported for 10 patients by Binder et al. (1992). The explicit demands of the two tasks are different

Table 3. Linear regression equations for the displacement of transections and standard deviations on line length (with the proportion of variance accounted for); mean (signed) percentage displacements; and the mean coefficient of variation. The expression "× line length" has been deleted after the multiplier in the regression equations

Patient R.H.	Right hand, right side	Right hand, left side	Left hand, left side	Left hand, right side
Displacement regression (V)	−2.12 + 0.017 (31)	−2.02 − 0.018 (26)	−2.91 − 0.073 (83)	−6.19 − 0.049 (52)
SD regression (V)	0.03 + 0.060 (92)	0.55 + 0.047 (94)	2.11 + 0.023 (59)	2.46 + 0.039 (69)
Mean % displacement	−1.50	−4.55	−12.15	−13.89
CV	5.99	5.59	5.61	7.56

and hence it is not surprising that they can dissociate. In cancellation tasks, substantial numbers of targets are presented simultaneously; the targets are randomly distributed physical stimuli, the detection of which requires visual search; and sequential motor responses are required to each stimulus array. By contrast, in bisection tasks (as deployed here), one stimulus is presented at a time; the target (the midpoint of the line) is not physically present, but must rather be *computed* by the subject; and only one response per trial is required. The two tasks, then, have little in common.

R.H.'s improvement when tested with the left hand is likewise unproblematic in principle. Like R.H., patient C.M., described in Halligan and Marshall (1989), showed severe left neglect on cancellation with the right hand, but near normal performance with the left hand. This improvement with the left hand is presumably due either to direct hemispheric activation of the right (damaged) hemisphere ("boosting") or to left spatio-motor cueing. Or, of course, to both processes.

The neuroanatomy that is relevant to task differences between cancellation and bisection remains unclear. Binder et al. (1992) reported that their patients who "showed neglect on the cancellation tasks but performed normally on line bisection had frontal or deep lesions." Yet neither of the patients who we have seen with this dissociation (H.D. and R.H.) had frontal lesions (on CT scan). The issue of differences in the type of neglect shown after anterior and posterior right hemisphere lesions cannot be regarded as resolved (Daffner et al., 1990; Kwon & Heilman, 1991; Lui et al., 1992).

Table 4. Means (and *SDs*) for the perceptual "directed-visual scan" line bisection task

	Left start	Right start
Session		
1	−14.4 (19.9)	−16.8 (7.9)
2	−5.6 (14.8)	−10.2 (10.8)
3	−6.2 (14.6)	−31.2 (7.9)

With respect to R.H., however, the real problem that requires explanation is why he shows reliable *right* neglect on bisection tasks performed with the left hand, and on the purely perceptual "directed-scan" bisection task.

If the "natural" inclination of the right hemisphere is to orient and attend to *left* space (Kinsbourne, 1993), it would seem that the right hemisphere (albeit damaged) has assured *primary* control of the perceptual line bisection task. There is behavioral evidence that the normal right hemisphere is specialized for judgments of relative spatial extent (Brown & Kosslyn, 1993; Kosslyn et al., 1989, 1992). Furthermore, a recent SPECT study has indicated that the right posterior parietal cortex and the right thalamus are maximally activated (in normal subjects) during the task of judging whether transected lines are correctly bisected (Marshall et al., 1994). In our perceptual directed-visual scan task, the left start condition explicitly cues the left end of the line while directing attention rightward (to follow the experimenter's pen); with right start, the right end of the line is initially cued, but the direction of guided scan is leftward. R.H.'s direction of spontaneous gaze is (atypically) leftward; we accordingly propose that the (significant) increase of right neglect with right start (*vs.* left start) is due to the leftward direction of the right start scanpath being consistent with his preferred direction of gaze.

By contrast, when the left hemisphere is explicitly activated by use of the right hand, the left hemisphere is not capable of opposing the intrinsic left bias of the right hemisphere. The final outcome thus reflects an appropriate balance between opposing orientational biases, and the displacement of transections is now within normal limits. We cannot (yet) specify the locus of information transfer that allows the reestablishment of balanced activation (on the line bisection task) when the manual response is programmed from the left hemisphere (= right hand). We repeat, however, that R.H. has intact visual fields and no hemiparesis. It would accordingly be reasonable to conjecture that the establishment of an appropriate balance of attention between the hemispheres (via cortical and subcortical commissures) is dependent upon activation within intact visual and motor cortices.

The conclusion that R.H. can easily attend to the left side of a single object (a line), but has more difficulty in attending to the left when multiple objects are presented (as in cancellation), is firm. One might accordingly consider the descriptive generalization that R.H. showed left neglect on tasks with multiple targets, but right neglect on tasks with single stimuli. This line of argument has been previously considered by Humphreys and Riddoch (1994), although their final phrasing of the generalization distinguished between within-object attention (single stimuli) and between-object attention (multiple stimuli). The assignment of within-object representations, they claim, is a (mainly) left hemisphere task, while the right hemisphere is dominant for the assignment of between-object spatial representations.

We can, however, summarize R.H.'s performance without making explicit reference to between- and within-object spatial relations. In R.H., the lesioned right hemisphere cannot oppose the attentional bias of the structurally less impaired left when the right hand (= left hemisphere) is used. The rightward attentional bias of the left hemisphere accordingly results in left neglect on cancellation (as in the vast majority of patients with appropriately placed right hemisphere lesions). As in other cases (Halligan et al., 1991b), significant improvement occurs (in left space) when use of the left hand for cancellation boosts the activation level of the right hemisphere (and provides a cue on the left).

Contrary to Humphreys and Riddoch (1995), we argue that line bisection (in particular the perceptual and computational aspects thereof) is (in the main) a right hemisphere task. In the purely perceptual bisection task, the lesioned right hemisphere continues to assume primary responsibility, and the attentional bias of that hemisphere to the left accordingly results in right neglect. R.H.'s left hemisphere does, however, become more highly activated when the right hand undertakes line bisection; the left hemisphere now succeeds in opposing the leftward bias of the right hemisphere, and final performance is significantly more accurate.

Riddoch et al. (1995) predicted that such "cases of paradoxical neglect (according to task)" should not be found after (unilateral) right hemisphere lesions. Their claim is based upon the (widely accepted) postulate that only the right hemisphere can attend to the full spatial field. As far as we know, R.H. is the first patient reported to have shown reliably different directional dissociations between tasks after primarily unilateral right hemisphere damage. How strong a counterexample he is to the claim of Riddoch et al. (1995) that "paradoxical neglect" of necessity involves left hemisphere (or callosal) damage is difficult to determine. The clinical and behavioral significance of the scattered white matter lesions in R.H.'s left hemisphere cannot be reliably assessed. It may be that they had sufficiently "weakened" R.H.'s left hemisphere (prior to his major right hemisphere stroke) to allow an anomalous pattern of performance to emerge subsequently. Alternatively, those small left hemisphere infarcts may have been (at all times) clinically silent. There are furthermore three patients with unilateral right hemisphere damage (b85, r32, and r43) reported by Robertson et al. (1994) who showed similar paradoxical neglect on one testing session; there was left neglect on star cancellation and right neglect on line bisection (when the right hand executed the response). Anomalous results of this nature are thus not (very) rare. Furthermore, this form of "paradoxical" neglect does not necessarily contribute to "an unmanageable explosion of dissociations" (Vallar, 1994) but can rather be interpreted with the same theoretical constructs that have been applied to "normal" cases of neglect.

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