Left unilateral neglect or right hyperattention?

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Article abstract—*Background:* Contradictory interpretations of left unilateral neglect suggest that it reflects either decreased attention toward the left or increased attention toward the right. According to the right-hyperattention postulate, increasing severity of neglect should result from an increasingly stronger bias toward the right. Thus, response times to right-sided targets should become progressively faster as neglect increases in severity across patients. The left-hypoattention postulate predicts that as neglect increases, progressively less-attentional resources are deployed in both hemispaces. Thus, response times to right targets should progressively increase with increasing neglect. *Methods:* We analyzed the distribution of manual response times to left- and right-sided targets in 24 patients with right hemisphere lesions and varying degrees of left neglect. *Results:* Not only the responses to left targets but also those to right targets became progressively slower as neglect increased, consistent with the hypoattention account. However, the two regression lines were not parallel. With increasing neglect, responses to left targets increased more steeply than those to right targets did. *Conclusions:* A rightward attentional bias is present in patients with left neglect, together with left hypoattention. However, this rightward bias is one of defective, and not enhanced, attention. **Key words:** Right brain damaged—Reaction time.

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Patients with left unilateral neglect fail to notice events occurring on their left. They bump into furniture on their left side, do not eat from the left part of the dish, and do not answer to people standing on their left. The first impression that one gathers from the observation of these patients is that they pay no attention to half of their visual world. However, the simple statement that unilateral brain damage may determine a deficit of attention for the contralateral hemispace does not capture one of the most striking aspects of neglect, namely, that neglect is more common, severe, and persistent after right hemisphere than after left hemisphere damage. To account for this basic characteristic of neglect, Heilman and Van Den Abell[1] proposed that the left hemisphere attends to contralateral space whereas the right attends to both contralateral and ipsilateral hemispaces. Thus, left hemispheric damage could be compensated for by right hemispheric attentional mechanisms, thereby only rarely provoking right neglect. Conversely, right cerebral damage would cause left neglect because the left hemisphere is unable to attend to the left hemispace. Thus, right hemisphere lesions should determine a severe deficit in attention for the contralateral hemispace but also a milder ipsilateral deficit, because less-attentional resources are now deployed in the right hemispace.[2] Consistent with this notion, left neglect patients may be impaired also in the right hemispace.[2-5]

In a different account of neglect, Kinsbourne[6,7] posited that each hemisphere shifts attention toward the contralateral hemispace by inhibiting the other hemisphere (the opponent processor model). In the normal brain, there is a tendency to rightward orienting supported by the left hemisphere. Right hemisphere lesions determine left neglect by exaggerating this physiologic rightward bias. Left hemisphere lesions would only rarely provoke right neglect because they release a right hemisphere attentional vector, which is less powerful than the left one. Left neglect does not reflect an attentional deficit but an attentional bias consisting of increased attention to the right. This bias is coupled with an abnormally tight focus of attention, which deprives patients of the possibility of a more general overview of the visual scene.[7] It follows that the sagittal midline plays no crucial role in neglect, every stimulus location being likely to be neglected if it is "left of" some other stimulus. This would account for the occurring of right omissions in left neglect,[2-5] because patients' attention would be captured by stimuli lying further to the right of those omitted.

These models have inspired major research efforts.[7,8] Here we focus on competing predictions stemming from these models on the distribution of manual reaction times (RTs) to lateralized visual stimuli. When responding to horizontally aligned stimuli, patients with left neglect should be slower for left-sided than for right-sided stimuli according to both hypotheses. However, according to the right-hyperattention model, this asymmetry should be observed, even when all the stimuli are presented in

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the right visual hemifield. Consistent with this prediction, Làdavas et al.[9] found that when presented with stimuli horizontally aligned in the right hemifield, patients with left neglect responded faster to right-sided than to left-sided targets. Right brain-damaged (RBD) patients without neglect, on the contrary, were faster for left-sided than for right-sided stimuli, probably because left targets appeared closer to the fovea. Of particular interest was the finding that neglect patients were faster for right targets than RBD patients without neglect. Neglect patients' attention for right targets seemed thus enhanced with respect to RBD control subjects, consistent with the right-hyperattention model. As Làdavas et al.[9] pointed out, according to this model, neglect patients should be faster for right-sided stimuli, even with respect to normal individuals without brain damage; this, however, would be an unlikely result, given that right brain damage lesions cause a deficit in arousal.[10] Indeed, subsequent RT studies[11-14] invariably found that left neglect patients were slower than control subjects when responding to right (ipsilesional) stimuli.

Another possibility consistent with these findings is that an important component of left neglect is a rightward bias of *defective* attention.[11,12,15] This could explain the evidence of an attentional gradient favoring events situated to the relative right of other events, coupled with the finding that even the rightmost events cannot elicit normal attentional processing.

Because neglect is not an all-or-none phenomenon but may vary in severity across patients, further testing of these issues is allowed. The left-hypoattention and the right-hyperattention models make opposite predictions concerning the distribution of RTs to right targets with increasing degrees of neglect. According to the hypoattention model, which postulates a bilateral attentional representation in the right hemisphere, severe damage to this system should also produce relative inattention for the right side, now attended to solely by the left hemisphere.[2] Thus, the hypoattention model predicts that responses to right-sided stimuli should be progressively slower as left neglect increases, paralleling the slowing of responses to targets presented in the left hemispace.

Conversely, the hyperattention model posits that left neglect is a direct consequence of enhanced attention to the right; thus, increasing severity of neglect should reflect an increasing amount of rightward bias, leading, in turn, to progressively faster RTs to right-sided stimuli.

If a rightward bias of impaired attention is present in neglect, then the relative weight of rightward attentional attraction and of attentional impairment should determine the direction of the RT distribution for right targets. RTs to right targets should progressively decrease with increasing neglect if rightward attentional attraction prevails or progressively increase if attentional impairment dominates. In this latter case, the variation of the RTs to right targets as a function of neglect severity should be less steep than the corresponding variation of RTs to left targets, because both rightward attentional attraction (leading to faster RTs) and attentional impairment (causing slower RTs) would increase with increasing neglect.

If, finally, a nondirectional attentional deficit, such as defective arousal, is aspecifically associated with right brain damage and not with neglect, its amount (and, therefore, its influence on RTs) should not correlate with the severity of neglect; no lawful relationship should therefore emerge between these two variables.

To test these predictions, we examined a group of RBD patients with left neglect using a quantitative measure of the amount of their spatial bias in paper-and-pencil tests and a task of speeded manual responses to lateralized visual stimuli. Hence, we were able to explore the distribution of RTs to left and right targets as a function of the severity of left neglect.

Methods. *Patients.* Twenty-four patients with left unilateral neglect consented to participate in the study. All had CT or MRI evidence of unilateral lesions in the right hemisphere (see table).

Tests of unilateral neglect. The presence and severity of unilateral neglect were assessed by using a battery of visuospatial tests,[16] which included tasks of line cancellation,[17] identification of overlapping figures,[15] and line bisection.[18] To measure subjects' spatial bias independent of their overall performance level, laterality scores derived from Bryden and Sprott[19] were used. The procedure was described elsewhere.[16] To summarize, the direction and amount of spatial bias were estimated by the following formula:

$$\lambda = \ln(X_R/X_L)$$

Values of X_R were computed by adding the following:

1. The number of items identified on the right side of the overlapping figures test (max = 10).
2. The number of lines canceled on the right half of the page of the line cancellation test (max = 30). Some patients with severe neglect (see table, Patients 18–24) started the test from the right side and did not cross the midline of the sheet; for these patients, the value (2) was replaced by the total number of neglected lines (max = 59).
3. The sum of the number of segments to the left of each subject's bisections (max = 42) in the line bisection task, in which the lines were divided into 20-mm segments.

Values of X_L were computed in analogous fashion (i.e., by adding the items of the left-sided identified superimposed figure to the number of left-sided cancelled lines and to the number of segments to the right of line bisection). Patients were considered to be affected by left neglect and included in the current study when their λ score exceeded the cutoff score defined by the mean +3 SDs of 30 control subjects' performance[16] (i.e., +0.104).

RT test. After a previously described procedure,[13] patients sat in front of a computer monitor at a distance of approximately 50 cm. Three horizontally arranged black circles, 14 mm in diameter, were displayed, the central circle being located at the center of the screen. Distance between

Table *Demographic and clinical characteristics of patients, who are ordered according to increasing severity of left neglect*

Patient no.	Sex, age, years of schooling	Onset of illness, d	Etiology	Locus of lesion	Visual field
1	M, 61, 8	135	Traumatic	TP	Normal
2	F, 66, 11	20	Neoplastic	TP, Th	Left extinction
3	F, 82, 7	7	Hemorragic	P	Left extinction
4	M, 77, 12	30	Ischemic	FP	Left extinction
5	M, 67, 18	37	Ischemic	Th	LSQ
6	M, 43, 8	119	Hemorragic	IC, Th	Normal
7	M, 67, 8	141	Hemorragic	FPT	Left extinction
8	M, 76, 5	15	Ischemic	P	LIQ + left extinction
9	F, 53, 7	76	Ischemic	FP	Left extinction
10	M, 46, 6	111	Ischemic	TFP	Left extinction
11	M, 80, 17	173	Ischemic	TO	LIQ
12	M, 69, 13	251	Ischemic	IC, BG	LH
13	M, 65, 12	52	Hemorragic	FP	Left extinction
14	M, 76, 7	4	Ischemic	TO	LH
15	M, 71, 7	20	Ischemic	FP	LIQ + left extinction
16	M, 62, 12	449	Hemorragic	TO	LH
17	F, 62, 15	113	Ischemic	O, Th	LH
18	M, 66, 13	12	Ischemic	FP	Left extinction
19	M, 73, 9	48	Hemorragic	FP	Normal
20	M, 63, 9	91	Hemorragic	FT	Left extinction
21	M, 43, 11	44	Traumatic	TP	LH
22	F, 69, 4	133	Ischemic	IC	LH
23	F, 73, 8	244	Ischemic	FP	LH
24	M, 53, 12	75	Ischemic	BG, IC	MA

F = frontal; T = temporal; P = parietal; O = occipital; Th = thalamic; IC = internal capsule; BG = basal ganglia; LIQ = left inferior quadrantanopia; LSQ = left superior quadrantanopia; LH = left hemianopia (with macular sparing); MA = rightward magnetic attraction of gaze on confrontation testing.

circles was 23 mm. During the test, the circles were always present on the screen. After an interval of 2000 msec, one of the circles became gray (target). When a right- or a left-sided target appeared, patients had to respond by pressing the computer spacebar with the index finger of the right hand as quickly as possible. Patients had to refrain from responding when the middle circle became gray (catch trials). Response time was measured from target onset to key press. The target disappeared when a response was made or after 5000 msec. After 1 block of 6 practice trials, 10 test blocks were presented, each including 4 right-sided and 4 left-sided trials plus 1 catch trial. The order of trials within a block was randomized. RTs ranging from 150 to 4500 msec were retained for subsequent analysis. RTs exceeding this range were considered as omissions.

Results. *Reaction times.* Figure 1 displays each patient's mean response time to left- and right-sided targets as a function of the severity of left neglect. RTs to left targets increased monotonically with increasing severity of left neglect, $F(1, 22) = 21.53$, $p < 0.001$, with a slope of 606 msec/U of λ score. More important, also RTs to right targets increased with severity of left neglect, $F(1, 22) = 8.28$, $p < 0.01$, with a slope of 201 msec/U. Thus, as can be seen in figure 1, the two regression lines are not parallel; as neglect increases, RTs to left targets increase more steeply than do RTs to right targets, as confirmed by the difference found between the two slopes, $t(44) = 2.73$, $p < 0.01$. In addition, the intercept of the regression line for RTs to left targets (1187 msec) was larger than the intercept of the line for right targets (887 msec), $t(44) = 2.46$, $p < 0.02$. This result predicts that our RT test would disclose a spatial bias (advantage for right versus left targets), even in the absence of biased performance on paper-and-pencil tests (λ score = 0); this was confirmed in other studies with the same RT paradigm,[12,13] including RBD patients without clinical signs of neglect.

Fifteen age-matched control subjects[13] had response latencies of 556 msec for left targets and 566 msec for right targets on the same task. Responses to right targets were 489 msec faster for control subjects than for neglect patients of the current study, $t(37) = -6.23$, $p < 0.0001$. When only the 11 patients with less-severe neglect ($\lambda < 0.5$) were taken into consideration, they were still 398 msec slower than control subjects for right targets, $t(24) = -6.18$, $p < 0.0001$.

These findings provide evidence against the presence of right hyperattention in our series of neglect patients. How-

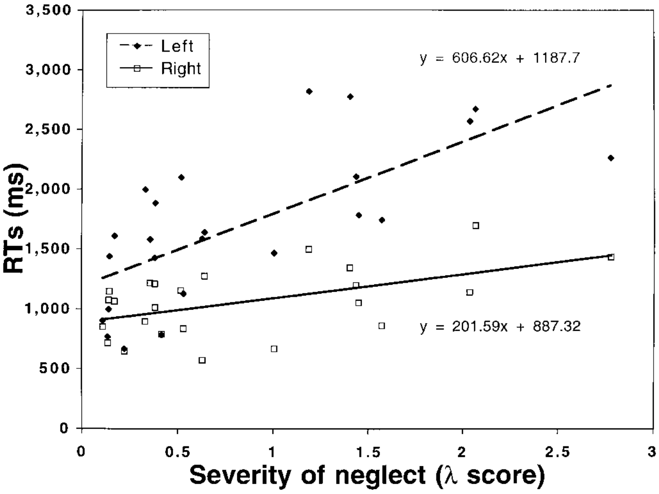

Figure 1. Regression plot of reaction times to left (filled symbols) and right (open symbols) targets as a function of the severity of left neglect (λ score).

ever, the possibility remains that right hyperattention existed only in a subgroup of patients, whose fast responses to right targets might have diluted the effect of hypoattention on RTs, thus producing a regression line that had the expected positive slope but to a lesser degree. To address this possibility, we selected the 10 patients with the fastest RTs to right targets and compared these RTs with those produced by age-matched control groups with right hemisphere lesions but no neglect[18] (n = 12) and without neurologic impairment[13] (n = 15). Even for this subgroup of neglect patients, RTs to right targets (mean, 784 msec; SD, 132 msec) were slower than those of control subjects [$t(23) = -4.05$, $p < 0.001$] and not faster than those of RBD patients without neglect (mean, 811 msec; SD, 263 msec; $t < 1$). These results argue against the presence in our series of a subgroup of neglect patients with right hyperattention.

Accuracy. By leaving the target on the screen for a long time (5 seconds) before response, we aimed at maximizing the accuracy of response in this simple target detection test. However, omissions did occur. Figure 2 displays the percentage of omissions as a function of the severity of neglect.

More left targets were omitted as neglect became more severe, $F(1, 22) = 21.53$, $p < 0.001$; the omission rate increased by 16% per unit of λ score. A tendency in the same direction was also present for right targets, whose omissions increased by 0.3% per unit of λ score, but this effect did not reach significance ($F < 1$).

Discussion. Taking advantage of quantitative evaluations of spatial bias, we were able to test alternative accounts of left unilateral neglect. We found that RTs to lateralized targets presented a lawful relationship with the severity of neglect as estimated by a laterality score. With increasing degrees of left neglect, not only RTs to left targets, but also RTs to right targets tended to increase. Results for accuracy of response were in the same direction, thus showing that patients were not trading speed for accuracy. Moreover, neglect patients (and even those with less-severe neglect) were definitely slower than control subjects when responding to both left and right targets. This pattern of results is more consistent with the left-hypoattention model[1] than with the right-hyperattention model[6,7] and suggests that the rightward attentional bias is a consequence, and not the cause, of the contralesional attentional deficit; attention would be biased toward the right only because the left-directing processor is hypoactive.[8]

However, if left hypoattention simply "spills over" to the right side as neglect becomes more severe, we would expect the RT regression line for left targets and that for right targets to be parallel. This was not the case, because as neglect increases, RTs to left targets increase more steeply than do RTs to right targets (figure 1). Thus, our results are best accounted for by a mixed model of neglect in which both a rightward attentional bias and defective attention play a role, but the attentional deficit prevails over the rightward bias. Previous studies suggested that unilateral neglect results from an association of several attentional impairments.[12,15,20,21] Our results are consistent with this notion and suggest that rightward attentional bias and defective attention concur in determining neglect severity.

One might argue that patients with severe neglect in our series did have increased attention to the right but were paying attention to spatial locations situated to the right of the entire stimulus array. If so, increasing severity of neglect would produce increasing RTs to right targets, because these targets would lay more to the left of the attentional focus. This account is unlikely because there was no object right of the rightmost stimulus that could attract patients' attention; informal observation of eye movements confirmed that during the course of the test, patients looked at the stimulus array and never to the right of it. Furthermore, by such an account, there should have been degrees of neglect corresponding to an exact location of the attentional focus on the right target, thus leading to fast RTs to right targets. If so, when contrasted with neglect severity, RTs to right targets would have as-

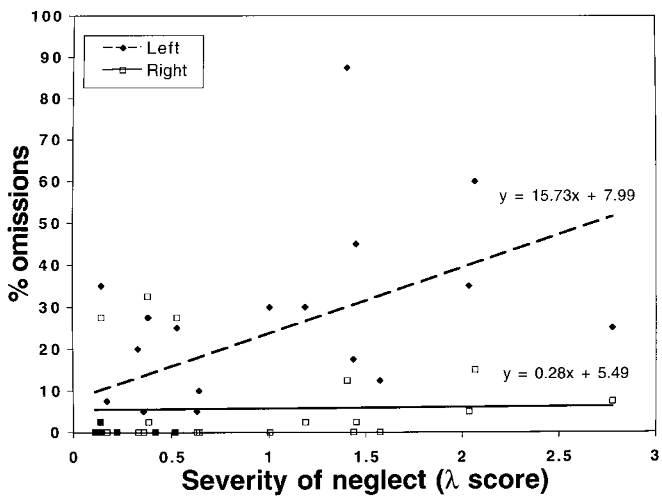

Figure 2. Regression plot of percentages of omissions to left (filled symbols) and right (open symbols) targets as a function of the severity of left neglect (λ score).

sumed a U-shaped curve and not the regression line apparent in figure 1.

Note that our measure of severity of neglect in paper-and-pencil tests was a laterality score that was independent of the overall level of performance. Thus, for example, increasing right-sided omissions on the cancellation test or the overlapping figure task with equal numbers of left omissions would decrease the amount of the score. Consequently, a nonlateralized pattern of omissions in paper-and-pencil tests, such as the one that would result from a nonspecific deficit in arousal or vigilance, could not inflate the neglect score. It follows from these considerations that the positive correlation that we found between the neglect score and the amount of RTs to both left and right targets cannot simply result from an arousal deficit aspecifically associated with right brain damage.[10]

The opponent processor model by Kinsbourne[6,7] has been important in stressing crucial aspects of left neglect, such as the "magnetic attraction" of attention exerted by right-sided objects, a prediction since confirmed in several laboratories.[11,15,22,23] What the current results suggest is that this spatial bias is not one of increased or normal attention but one of defective attention. This notion is consistent with PET data showing a widespread hypometabolism in both the lesioned and the intact hemisphere in neglect[24] and perhaps best exemplified by the performance of some patients with severe left neglect on line cancellation tasks. These patients not only neglect lines on the left side but also perseverate in that they cross out several times the lines situated in the rightmost extremity of the sheet. Thus, patients' attention is repeatedly attracted by the rightmost lines; however, their attention is insufficient to recognize that these lines are already crossed.

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