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Egocentric frame of reference: its role in spatial bias after right hemisphere lesions

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Abstract

The reference shift hypothesis of unilateral neglect holds that spatial bias in left neglect stems from a rightward deviation of patients' egocentric frame of reference (ER). Twenty five unselected right brain-damaged patients participated in a straight-ahead pointing task to assess the position of their ER (Experiment 1). A rightward ER shift emerged only in the subgroup of patients with extensive parietal lesions. In Experiment 2, we found that the position of the ER did not predict the outcome of various visuospatial neglect tests ($r = 0.07$ to 0.27). In Experiment 3, no significant positive correlation emerged between the ER position and visual ($r = 0.26$) or tactile ($r = -0.48$) extinction. Two further experiments examined the relationships between the ER position and patients' performance on a reaction time test of directional motor bias (Experiment 4), and on a test of response times to lateralised visual stimuli (Experiment 5). Results showed that the ER position did not predict the distribution of accuracy scores or response times in either task (Experiment 3: accuracy: $r = 0.06$; response times: $r = 0.16$; Experiment 4: accuracy: $r = 0.09$; response times: $r = 0.04$). We concluded that the position of the ER plays no crucial role in the behavioural consequences of spatial bias induced by right hemisphere lesions. © 1999 Elsevier Science Ltd. All rights reserved.

Keywords: Unilateral neglect; Spatial bias; Egocentric frame of reference

Abbreviations: ER, Egocentric frame of reference; RBD, Right brain-damaged; RT, Reaction time

1. Introduction

Patients with right hemisphere brain lesion who suffer from left hemineglect show a directional bias toward the right side of space when perceiving and acting in their environment. A number of theories have been advanced to account for this often dramatic and pervasive behavioural pattern, but neglect has up to now proved elusive for a unitary explanation, and there is no consensus about its causal mechanisms [25]. Recently the hypothesis has been proposed that the crucial mechanism leading to neglect is the disturbed transformation of sensory input into a supramodal egocentric frame of reference (ER), causing in turn a deviation of this reference frame toward the side ipsilateral to the brain lesion [36, 58]. We shall refer to this as the *reference shift hypothesis* of neglect. This hypothesis draws on the more general notion that spatially-directed behaviour is coded "in a system of coordinates (a motor 'map' of space) referred to the body axis, different from the visual map on which the retinal position of objects is specified [31, p. 87]". This egocentric coordinate system is normally superimposed to the sagittal middle, but a unilateral brain lesion would produce a deviation of the ER through an imbalance between the bilateral neural processes which build this representation [31, 62].

The concept of a supramodal coordinate system used for visuomotor and exploratory behaviour has been postulated on the grounds that the integration of data from different sources of sensory input (visual, tactile, vestibular, auditory, proprioceptive) is necessary for an organism to interact effectively with its environment. A unique representation would perform the computations to solve, for example, the problems posed by the spatial distortion of sensory and motor primary cortical representations (e.g., there is no isomorphism between the retina and its cortical projections, the fovea being overrepresentated in

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V1), by the fact that receptive surfaces are constantly moving, and by the different coordinate systems used by different primary sensory and motor maps [56].

An efficient way of building this single coherent frame of reference would be to code it in terms of egocentric coordinates relative to the sagittal middle; this putative space representation is the egocentric frame of reference postulated by the reference shift hypothesis of neglect. It has to be noted, however, that it is not necessary to postulate such a single central representation of the ER; multisensory integration could be performed by a distributed mechanism, as a neural network for transforming one set of sensory vectors into other sensory reference frames [56]. Furthermore, several independent mechanisms of this type could be at work in parallel in different brain areas [55]. Whatever the mechanism in use, it should provide the possibility of locating stimuli relative to the observer, of acting with reference to them and of representing the position of the body in space. In the hypothesis of a frame of reference coded in egocentric coordinates, it has been suggested that the trunk vertical midline, and not the head or visual field midlines, constitutes the anchor of this representation [42]. Thus, the usual way of testing the perceived direction of the ER is to ask subjects to point straight ahead while blindfolded and to record this subjective position [31, 63].

If left neglect patients suffer from an ipsilesional deviation of their ER, then they are expected to point to the right of the objective midline on this task. This pattern of performance has indeed been described in some studies. Heilman, Bowers and Watson [30] tested five right brain-damaged (RBD) patients with left neglect and five left brain-damaged patients, and found that both groups erred toward the side ipsilateral to the brain lesion; RBD neglect patients, however, showed a greater ipsilesional deviation than left brain-dmaged patients. Because the pointing task did not require visual of somesthetic input, Heilman and coworkers interpreted their results in neglect patients in terms of a directional motor disorder ('hemispatial akinesia'). The finding of an ipsilesional shift of the subjective sagittal middle in left neglect was replicated in one patient with a proprioceptive straight-ahead pointing task [13] and in three patients with a visual straight-ahead pointing task [36]. Perenin found a mean rightward deviation of about 9° in a group of 25 left neglect patients using a straight-ahead pointing task performed in darkness [50, Fig. 5].

These findings support the reference shift hypothesis of neglect, which predicts an association between left neglect and rightward deviation on the straight-ahead pointing task, both phenomena being consequent upon an underlying distortion of the ER. However, recent evidence suggests that this association may not be the rule. Hasselbach and Butter [28] found an ipsilesional bias in perceiving straight ahead (in a visual condition) in two patients with extensive right parietal lesions, but not in three RBD patients whose lesions largely spared the parietal lobe, even though the latter patients showed left neglect signs. A dissociation between left neglect and rightward shift of the ER was thus demonstrated. Moreover, in another study [18] employing a similar visual paradigm (in which patients were required to stop a moving spot as it crossed their perceived midline), a rightward ER deviation was observed only when the direction of the spot was from the right to the left, and not in the opposite condition, in which neglect patients were accurate in locating their perceived egocentre; on the other hand, in a proprioceptive straight-ahead pointing task no evidence of ER displacement was found in the neglect group.

In a recent study [10] we addressed more directly the issue of the interaction between neglect and ER position, by examining the relationship between the proprioceptive straight-ahead pointing task and a battery of neglect tests. We studied a series of six RBD patients, three showing signs of left unilateral neglect, three without signs of neglect. Results showed that all patterns of dissociation were possible between left neglect and rightward deviation in the pointing task. Patients showed leftward, rightward or no significant deviation when pointing straight ahead, irrespective of the presence or absence of neglect signs. Particularly impressive was the performance of a left neglect patient (case 2), who pointed significantly to the *left* (that is, toward his neglected hemispace). Case 2 thus showed a deviation of his ER in the opposite direction for that predicted by the reference shift hypothesis of neglect. Our findings thereby suggested that there is no causal relationship between the position of the ER and left neglect. This conclusion was based on the classical neuropsychological method of inferring the functional independence between two signs by finding double dissociations between these signs in individual case studies. Nevertheless, our data could in principle have suffered from possible idiosyncratic differences, because they were obtained in a small series of patients, and hence could not be conclusive to disprove the reference shift hypothesis of neglect (note, however, that also data showing an ipsilesional ER deviation in neglect were mostly based on small groups of patients). An alternative approach for determining whether two tasks load on the same process is to examine the correlation between these tasks in a group study [53]. Thus, for example, low correlations between the direction and magnitude of the deviation of the ER and behavioural measures of neglect in a group of RBD patients would provide converging evidence that the position of the ER is not causally related to neglect. Experiments 1 and 2 of the present study examined the position of the ER in a group of 25 unselected RBD patients and the relationship of this position with patients' performance on several neglect tests.

Another issue was left open by our previous study [10]. We found that RBD patients without clinical signs of neglect may show an ipsilesional shift of their ER. Thus, this deviation might be related to forms of spatial bias other than clinically manifest neglect. To address this issue, we investigated whether the position of the ER was related to visual or tactile extinction (Experiment 3), to a directional motor bias in producing lateralised arm movements (Experiment 4), or to a bias when producing central manual responses to lateralised visual stimuli (Experiment 5). In this way, we explored the relationships between the position of the ER and patients' performance in each of several levels of spatial processing ranging from perception to action.

2. Subjects

Twenty five right brain-damaged patients and 22 age-matched control subjects free of neurological damage (mean age: 62 years; range 47–80) consented to participate in this study. Patients were consecutively tested upon their admission in neurological or rehabilitation units. The only inclusion criteria was their ability to perform all the experimental tasks. Patients did not show any clinical evidence for ipsilesional motor or proprioceptive deficit, or misreaching with the right arm. Table 1 reports patients' demographical and clinical data. All subjects were right handed as assessed by means of a laterality questionnaire [16].

3. Experiment 1: straight-ahead pointing task

The aim of the present experiment was to assess the position of the egocentric reference in an unselected group of RBD patients, by using the classic proprioceptive straight-ahead pointing task [31, 63].

Most previous studies testing the link between the position of the subjective median plane and left neglect signs have employed relatively small groups of brain-damaged patients, who were selected on the basis of the presence or absence of left neglect signs [10, 13, 30, 35–38]. The fact that these studies were based on small and selected patient samples might have affected the reliability of the obtained results. Consequently, the interpretation of the observed rightward ER deviation as typical of left neglect might not be warranted.

In Experiment 1, we tested a comparably larger group of unselected right brain-damaged patients in order to explore more thoroughly the influence of a unilateral brain lesion on the structure of the egocentric frame of reference.

3.1. Procedure

Subjects were seated blindfolded in front of a large graduated table. Their trunk and head were aligned at 0°, the sagittal middle corresponding to the objective centre of the table. Trunk and head positions were carefully monitored by the experimenter throughout the task.

Before each trial, the subjects' right arm was positioned at one of four starting points, from which they had to point with their index finger toward the imaginary position they felt to be exactly in front of them, moving the arm along the table. Subjects performed 16 trials, four with each of the four stating positions: 30° or 15° left (-30°, -15°) or right ($+30^\circ$, $+15^\circ$) of the objective centre of the table. There was no time limit and the finger position was recorded when the subject estimated that his index was pointing straight ahead. The pointing error was measured to within half a degree, by determining the distance between the pointing position and the objective centre, and carried a minus sign for leftward pointings and a plus sign for rightward pointings.

Control subjects' performance on this task was compared to the objective mid-sagittal plane with a two-tailed t test, while brain-damaged subjects' performance was compared with a two-tailed t test to both the objective mid-sagittal plane and the performance of control subjects.

3.2. Results and discussion

Normal subjects tended to point slightly to the right of the objective sagittal middle with their right hand (mean $= +2.54^\circ$; S.D. $= 6.71$, range -24, $+29$; $t = 1.79$, $d.f. = 21$, $P = 0.09$), thus confirming previous results obtained with a group of younger subjects [10].

Taken as a group, RBD patients also made a rightward deviation ($+1.11^\circ$), which proved to be not significant neither relative to the objective middle ($t = 0.40$, $d.f. = 24$, $P > 0.6$), nor relative to normal controls' results ($t = -0.44$, $d.f. = 45$, $P > 0.6$). Individual data are reported in Table 1.

As previously noted, recent evidence suggests that the ipsilesional bias in perceiving straight ahead can be found after extensive right parietal lesions, but not after right-sided lesions which largely spare the right parietal lobe [28]. We thus divided our RBD patients in two subgroups on the basis of the presence ($n = 14$) or absence ($n = 11$) of extensive parietal lesion (see Table 1). The 'parietal' subgroup included patients 3, 5-8, 10, 12–14, 17–19, 23 and 25. Lesion chronicity was not significantly different in the two subgroups ($t = 1.44$, $d.f. = 23$, $P > 0.16$). An analysis of variance performed on pointing data for each RBD subgroup and for control subjects revealed a significant group effect ($F = 7.56$, $d.f. = 2.44$, $P < 0.005$). Post hoc pairwise comparisons (carried out using Fisher's protected least significant difference) indicated a significant difference in performance between patients with extensive parietal lesions, who deviated rightward ($+5.26^\circ$, S.D. $= 6.87^\circ$), and patients without extensive parietal lesions, who deviated leftward (-7.36°,

Table 1
Demographical and clinical characteristics of RBD patients, position of the perceived body midline and t values against zero and controls' performance (Experiment 1); patients are ordered according to the approximate severity of their neglect

Patient	Sex, age, years of schooling	Onset of illness (days)	Aetiology	Locus of lesion	ER (degrees)	S.D.	$t/0°$ (d.f. = 15)	t/controls (d.f. = 15)
1	M, 52, 9	153	Haemorragic	IC, Th	−9.94	4.55	8.74*	7.39*
2	M, 53, 18	39	Ischemic	IC, BG	−31.94	8.56	14.93*	15.21*
3	F, 51, 8	29	Ischemic	FP	+11.31	12.01	3.76	3.04*
4	M, 53, 5	5	Haemorragic	IC, BG	−5.75	2.74	8.39*	5.55*
5	M, 55, 15	77	Haemorragic	FP	−11.16	3.55	12.50*	8.70*
6	F, 72, 5	33	Haemorragic	FPT	+7.97	4.96	6.41*	3.07*
7	M, 40, 5	33	Ischemic	FTP, BG	−6.88	4.50	6.10*	5.62*
8	M, 68, 8	77	Ischemic	FP	+9.69	5.36	7.25*	3.96*
9	M, 57, 5	129	Ischemic	FT, BG	−1.19	14.99	0.07	1.1
10	M, 46, 5	57	Ischemic	FPT	+6.19	11.71	2.11	1.27
11	M, 46, 5	113	Haemorragic	F	−0.31	4.69	0.26	1.7
12	M, 69, 7	151	Ischemic	FPT	+12.44	3.03	16.36*	6.38*
13	M, 61, 8	135	Traumatic	TP	+11.88	15.38	4.55*	2.66*
14	M, 77, 12	30	Ischemic	FP	+5.22	11.62	1.79	0.92
15	M, 67, 18	37	Ischemic	Th	+11.44	23.26	1.96	1.74
16	M, 43, 8	119	Haemorragic	IC, Th	−23.63	4.03	23.44*	16.05*
17	M, 67, 8	141	Haemorragic	FPT	+8.75	3.86	9.09*	3.83*
18	F, 53, 7	76	Ischemic	FP	+3.78	2.83	5.33*	0.78
19	M, 46, 6	111	Ischemic	TFP	+1.56	8.38	0.74	0.44
20	M, 65, 12	52	Haemorragic	T(P)	−11.88	4.56	10.43*	13.26*
21	M, 60, 12	205	Ischemic	O	+0.81	6.57	0.49	0.91
22	M, 63, 9	91	Haemorragic	FT	+4.19	7.02	2.38*	0.79
23	M, 43, 11	44	Traumatic	TP	+3.75	3.69	4.06*	0.75
24	M, 62, 12	449	Haemorragic	TO	−12.19	4.45	2.74*	8.80*
25	M, 53, 12	75	Ischemic	BG, IC, P	+9.63	25.16	1.53	1.29

F, Frontal; T, Temporal; P, Parietal; O, Occipital; Th, Thalamic; IC, Internal capsule; BG, Basal Ganglia; (P), Marginal parietal involvement; ER, position of the egocentric reference; $*P < 0.05$.

S.D. = 12.52°; $P < 0.001$). RBD patients with substantial sparing of the parietal lobe also erred leftward when compared with controls' performance ($P < 0.005$). RBD patients with extensive parietal lesions, however, did not differ from controls, possibly on account of the presence, in the parietal group, of patients who pointed leftward (cases 5 and 7), and also because of the variability in performance observed in the control group. When compared to the objective midline, however, the rightward deviation of the parietal group resulted to be statistically significant ($t = 2.86$, *d.f.* = 13, $P = 0.01$); the leftward deviation shown by the RBD group without extensive parietal lesion was marginally significant ($t = -1.95$, *d.f.* = 10, $P = 0.08$).

Thus, RBD patients with extensive right parietal lesion showed an ipsilesional shift of their ER, while RBD patients with a substantial sparing of parietal cortex tended to exhibit the opposite pattern, i.e,. a contralesional deviation of their ER. Our results seem broadly consistent with Hasselbach and Butter's [28] finding of an association between right parietal lesions and rightward shift of the subjective midline.

To assess the effect of the starting point upon subjects' performance on the straight-ahead test, repeated measures analyses of variance were conducted for each group of subjects (parietal, non-parietal, control) with the starting point (−30°, −15°, +15°, +30°) as within factor. Results showed that both subgroups of RBD patients showed an effect of the starting point (parietal: $F = 3.08$, *d.f.* = 3, 39, $P < 0.05$; non-parietal: $F = 3.39$, *d.f.* = 3, 33, $P < 0.05$), whereas control subjects did not ($F < 1$). Regression analyses revealed that, for patients with parietal lesion, the amount of rightward shift increased monotonically with the increasing rightward position of the starting point ($F = 4.08$, *d.f.* = 1, 54, $P < 0.05$), with a slope of 0.15°/degree; patients without parietal damage showed a marginally significant tendency to increase their leftward deviation when starting from more leftward positions ($F = 3.24$, *d.f.* = 1, 42, $P = 0.079$).

Figure 1 shows that while patients with extensive parietal lesion produced a massive rightward deviation (+14.6°) when started 30° to the right of the objective middle, RBD patients without extensive parietal lesions produced a massive leftward deviation (−11.88°) when started 30° to the left of the objective middle. In both cases, starting from the opposite side reduced this bias. This pattern of performance produced the two parallel slopes of Fig. 1.

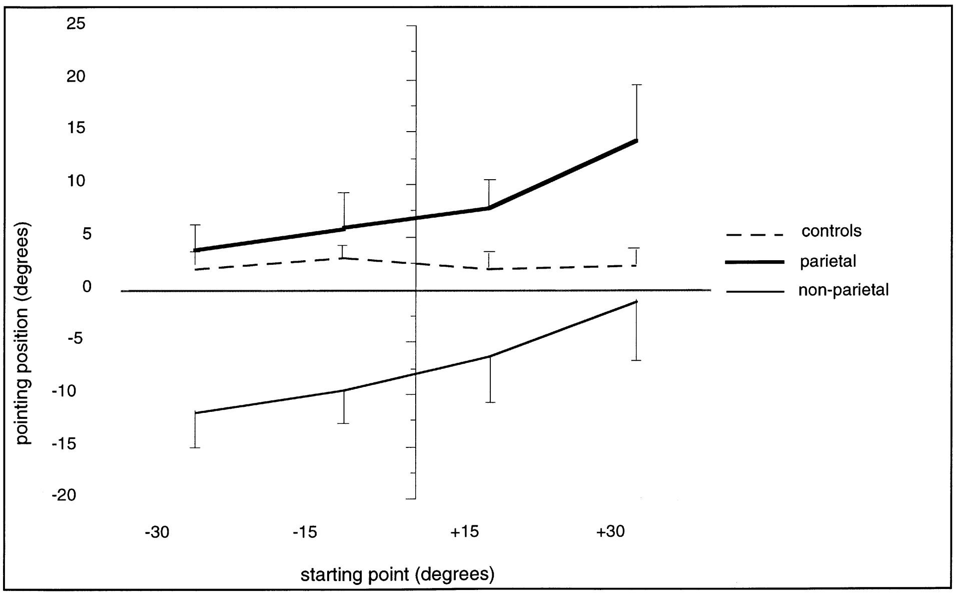

Fig. 1. Experiment 1: effect of the starting point on the final pointing position for RBD patients (with or without extensive parietal lesions) and control subjects. The error bars represent 1 S.D.

4. Experiment 2: neglect tests

Following the reference shift hypothesis, in left neglect the subjective body midline is shifted towards the right side because the system which builds the egocentric frame of reference works with a systematic rightward error [35]. Consequently, patients' subjective space is split into a left and a right half by what they now perceive as their body midline. In turn, this distortion determines a systematic rightward bias in exploratory behaviour, which results in signs of left neglect. Thus, for example, the position of the radial line beyond which items are neglected in cancellation tests should be strictly correlated with the position of the perceived body midline. Similar considerations hold for rightward displacements of the subjective centre in line bisection and for left omissions in identifying or copying composite figural arrays.

It follows from these considerations that measures of rightward bias on these tasks should monotonically increase with the amount of rightward ER deviation. In Experiment 1 we examine this possibility by computing the correlations between the position of the ER and laterality scores derived from tests of cancellation, line bisection, identification of overlapping figures and copy of a complex drawing.

4.1. Procedure

The patients were submitted to a battery of paper-and pencil visuospatial tests. Here follows a short description of the component tasks.

In the overlapping figures task [20], patients are requested to identify five patterns of overlapping linear drawings of common objects. Each pattern included a central object (e.g., a basket) with a pair of objects depicted over each of its sides (e.g., a lamp and a watch on the left side, a pipe and a key on the right side).

In the cancellation tests, a horizontal A4 sheet is presented to the patient, who is asked to cancel stimuli of various kinds which are scattered on it: lines [1], As (among other letters [47]), or silhouettes of bells (among other objects [22]).

We used a version of the line bisection test originally described by D'Erme et al. [15]. It consisted of eight lines horizontally disposed in a vertical A4 sheet, in a fixed random order. There were three 62 mm samples at 38, 81 and 124 mm from the left margin of the sheet, three 100 mm samples at 17, 62 and 90 mm from the margin, and two 180 mm samples at 14 mm from the margin.

Finally, we asked patients to copy a linear drawing representing a house and four trees (landscape drawing task [21]), presented on a horizontal A4 sheet.

To obtain a quantitative measure of spatial bias in each component test of the visuospatial battery, we computed laterality scores for each of the neglect tests using the following procedure. For the line bisection test, we calculated the cumulated percentage of deviation from the true centre for all the lines. Rightward deviation assumed a positive sign, whereas leftward deviations carried a negative sign. For the overlapping figures test and each of the cancellation tests, we estimated the bias toward the right side by using a laterality score, defined as

$$(x_1 - x_2)/(x_1 + x_2).$$

Values for x_1 were given by the number of items identified on the right side for the overlapping figures test, or the number of items cancelled on the right half of the page for the cancellation tests. Values for x_2 were computed in an analogous fashion, i.e., by using the number of left-sided identified overlapping figures and the number of left-sided cancelled items. One advantage of this laterality score is that it provides a quantitative estimate of spatial bias which is independent of the overall level of performance (e.g., of the total number of cancelled lines). Its possible range is from -1 (all the items reported or cancelled on the left side, none on the right side) to $+1$ (the opposite situation). A correction was needed for cancellation tasks performed by patients with severe neglect, who cancelled only the rightmost items, without crossing the midline. In order not to underestimate their neglect, the laterality score obtained by these patients was augmented by the proportion of the number of neglected items on the right side (max $+1.48$ for line and letter cancellation, and $+1.47$ for bell cancellation, corresponding to a single item cancelled on the right).

The landscape copy was evaluated by assigning 2 points to each item completely omitted, 1 point to each item whose right half was copied, and 0 points to each item completely copied. The obtained scores could thus range from 0 (all the items completely copied) to 9 (only the right half of a single item copied).

In Experiments 2–5, the reliability of correlation coefficients was assessed by means of z tests for hypothesised correlation set to 0; $n = 25$ unless otherwise specified.

4.2. Results and discussion

Results of neglect tests are displayed in Table 2. Patients 7–25 showed signs of left neglect in one or more visuospatial tests.

Several positive correlations emerged among laterality scores obtained from neglect tests (Table 3). These findings provide evidence for some internal coherence among these tests, and suggest that common mechanisms of spatial bias were at work in determining our patients' performance (see also [26]). Accessorily, these findings also indicate that our patient sample was large enough to allow for significant correlations to emerge.

Among left neglect patients, cases 8, 12, 13 and 17 presented an ipsilesional deviation of their ER when pointing straight ahead (see Table 1), as predicted by the reference shift hypothesis of neglect. However, patients 9, 11, 19 and 21 were remarkably accurate when estimating their egocentre. Other neglect patients, such as cases 18, 22 and 23, showed a rightward shift that was not different from controls'. Three further left neglect patients (cases 16, 20 and 24), pointed clearly leftward of the true midline. Among patients who did not show signs of left neglect on visuospatial testing, patients 1, 2, 4 and 5 pointed leftward, and patients 3 and 6 pointed rightward of their body midline. We were thus able to replicate our earlier findings [10] that every possible pattern of dissociation can occur between left neglect and rightward ER deviation.

This qualitative evaluation of our results was confirmed by the obtained correlation coefficients between the position of the ER and the amount of spatial bias in each neglect test. The coefficients were as follows. Identification of overlapping figures: $r = 0.27$ ($z = 1.29$; $P > 0.19$); line cancellation: $r = 0.07$ ($z = 0.35$; $P > 0.7$); line bisection: $r = 0.10$ ($z = 0.47$; $P > 0.6$); letter cancellation: $r = 0.22$ ($z = 1.06$; $P > 0.2$); bell cancellation: $r = 0.14$ ($z = 0.63$; $n = 23$; $P > 0.5$); landscape copy $r = 0.07$ ($z = 0.35$; $P > 0.7$).

Results of Experiment 1 suggested that a rightward deviation of the ER may be present only in RBD patients with extensive parietal lesion (see also [28]). Thus, it is possible that only in these patients a deviation of the ER resulted in neglect signs. To test this possibility, we computed the correlation coefficients between the ER position and each of the neglect tests for the subgroup of patients with extensive parietal lesion ($n = 14$). Again, no reliable correlation emerged ($r = -0.23$ to 0.26, all Ps n.s.).

In sharp contrast with the reliable positive correlations observed among neglect tests, very low and statistically unreliable correlations were thus found between the position of the ER and each of the paper-and-pencil neglect tests.

Results of Experiment 2 replicate in a larger series of patients and with a greater number of neglect tests our previous findings obtained with six RBD patients [10], and support our proposal that the position of the ER is not a useful tool to predict patients' performance on paper-and-pencil visuospatial tests.

One might argue that the lack of significant correlation between performance on neglect tests and the position of the ER depends on the fact that the proprioceptive straight-ahead is not an adequate measure of the ER. Because this task is a manual pointing task, motor problems could influence its outcome independently of the presence of neglect. However, this account does not explain our observation of neglect patients who were accurate on the proprioceptive straight-ahead task. It is difficult to imagine confounding factors whose effect is to restore normal performance in an otherwise biased task. Moreover, in the only non-motor alternatives to the proprioceptive straight ahead task, subjects either say whether a visual stimulus presented at various positions along the horizontal axis is perceived right or left of the body midline [28], or stop a moving spot as it crosses the midline [18, 36, 38, 41, 50]. These tasks are performed under visual control, and can therefore be performed not only by using an egocentric frame of reference, but also by using a retinocentric or an allocentric frame of reference; if so, these tasks would be unsuitable to test the *egocentric* reference hypothesis of neglect. Moreover,

Table 2
Patients' performance (left/right correct responses) on the neglect battery (Experiment 2) and on the extinction tests (Experiment 3)

Patient	Overlapping figures (max. 10/10)	Line cancellation (max. 30/30)	Letter cancellation (max. 30/30)	Bell cancellation (max. 15/15)	Line bisection (% deviation)	Landscape drawing (max. 10: see text)	Visual DSS	Tactile DSS
1	10/10	30/29	29/25	14/14	+7.38	9	0/18 (3)	3/18 (3)
2	10/10	30/30	29/30	—	0.00	9	5/6 (1)	1/12 (2)
3	9/10	30/30	25/26	12/14	−1.43	10	5/6 (1)	6/6 (1)
4	10/10	30/30	27/30	12/15	+1.67	10	15/18 (3)	6/6 (1)
5	10/10	30/30	30/26	13/14	+3.09	10	8/12 (2)	2/6 (1)
6	10/10	30/30	30/30	13/14	+8.33	10	6/6 (2)	11/12 (2)
7	9/9	30/30	28/30	14/15	+12.38	10	6/6 (1)	7/12 (2)
8	10/10	25/30	23/25	11/12	+0.24	10	13/18 (3)	7/12(2)
9	7/8	29/30	28/30	14/15	+7.38	4	L Hemianopia	L Hemianesthesia
10	8/8	22/30	17/25	9/13	−5.00	9	7/18 (3)	4/12 (2)
11	10/10	30/30	0/21	2/15	+0.24	10	0/12 (2)	5/18 (3)
12	10/10	30/30	4/28	0/14	+5.95	9	0/12 (2)	5/12 (2)
13	10/10	22/27	18/23	13/15	+2.86	10	6/6 (1)	6/6 (1)
14	10/10	28/30	12/23	—	+16.19	8	3/12 (2)	3/6 (1)
15	9/10	29/30	0/27	0/10	+19/76	9	1/6 (1)	6/6 (1)
16	10/10	15/21	30/30	12/14	+11.67	10	6/6 (1)	0/6 (1)
17	9/9	14/30	18/23	13/15	+2.62	5	0/6 (1)	3/12 (2)
18	7/10	24/30	1/22	13/12	+29.52	10	2/6 (1)	10/18 (3)
19	7/9	25/30	12/22	1/14	+34.52	7	0/8 (2)	5/18 (3)
20	10/10	2/23	2/23	4/11	+3.81	6	2/12 (2)	0/12 (2)
21	7/5	28/29	0/2	0/2	+89.76	5	L Hemianopia	0/6 (1)
22	5/10	0/21	1/22	0/13	+26.19	6	0/12 (2)	5/12 (2)
23	7/9	0/22	0/25	4/15	+43.33	6	0/12 (2)	12/12 (2)
24	9/7	6/29	0/23	0/6	+52.86	6	L Hemianopia	7/12 (2)
25	1/8	0/12	0/13	0/14	+78.81	5	Magnetic attraction	0/6 (1)

—, Missing data; DSS, Double simultaneous stimulation (left/right correctly reported stimuli; the number of repetitions of the basic sequence is given in parentheses); L, Left.

Table 3
Correlation matrix for neglect tests ($n = 25$ unless otherwise specified)

	Overlapping figures	Line cancellation	Letter cancellation	Bell cancellation ($n = 23$)	Line bisection	Landscape drawing
Overlapping figures	—					
Line cancellation	0.64**	—				
Letter cancellation	0.29	0.54**	—			
Bell cancellation	0.17	0.40	0.83**	—		
Line bisection	0.37	0.48*	0.72**	0.72**	—	
Landscape drawing	0.28	0.60*	0.46*	0.48*	0.58**	—

*$P < 0.05$; ** $P < 0.01$.

visually-based tasks of straight ahead involving moving spots are influenced by the direction of the movement; the starting point of the moving spot determines the subjects' perception of its crossing the midline [18], much in the same way as the direction of a spot moving along a horizontal line influences the subjects' perception of the middle of the line [9, 12, 14, 44, 51]. For these reasons, pointing straight ahead without the aid of vision is currently the most employed measure of the position of the ER [10, 13, 24, 30–32, 43, 49, 52, 63].

5. Experiment 3: visual and tactile extinction

Contralesional extinction, or the failure to report the contralesional stimulus on double simultaneous simulation with normal detection on single presentation, is often described in neglect patients, both in the visual and tactile modalities (it can also be present in the auditory and olfactive modalities).

The relationships between neglect and extinction are not clear, neither are the causal mechanisms of extinction

[4]. Although neglect patients usually show visual extinction [20], and may continue to do so after neglect recovery [33, 34], double dissociations have been documented between these two deficits [17, 23]. It is thus possible that distinct mechanisms, as a low-level sensory deficit or a higher level attentional deficit, may determine extinction [61].

Be that as it may, it remains that extinction can be regarded as a spatially-based deficit, in that detection of contralesional stimuli is impaired by the concurrent presentation of ipsilesional stimuli. It was therefore of interest to examine whether a correlation existed between visual or tactile extinction and a distortion of the egocentric frame of reference.

5.1. Procedure

Patients' visual field and the presence of visual extinction were assessed by using the confrontation method. Following a previously described procedure [20], the patient was seated at a distance of about 1 m from the confronting examiner, and requested to fixate his or her gaze on the examiner's nose. Once fixation was stable, the examiner, who held his or her arms outstretched, briefly moved his or her fingers either in one hemifield or in both hemifields simultaneously. Patients were asked to report each movement of the examiner's fingers. In its basic form, the test consisted of six single unilateral stimuli (respectively delivered in left and right upper visual quadrants, left and right lower visual quadrants, and in left and right hemifields along the equatorial line) and six double simultaneous stimuli (two in the upper visual quadrants, two in the lower visual quadrants, and two on the equatorial line). The stimuli were delivered following a previously randomised sequence, which could be repeated up to three times (see Table 2). Patients were classified as suffering from left hemianopia when they consistently failed to report the stimuli delivered in their left hemifield. Patients were considered as affected by left upper or lower quadrantanopia when they failed to report all the stimuli administered in the corresponding visual quadrant. Left visual extinction was defined by the dissociation between correct report (at least on one occasion) of a single stimulus and failure to report a stimulus occurring in the same spatial location when a concurrent stimulus was simultaneously administered on the other side.

To assess tactile extinction, the examiner lightly touched the blindfolded patient's hands, feet or cheeks. In its basic form, the test consisted of six single unilateral stimuli (left and right hands, left and right feet, left and right cheeks) and six double simultaneous stimuli (both hands, both feet or both cheeks, each repeated twice), delivered according to a previously randomised sequence. The patient was asked to report the occurrence and location of the stimulation. The stimulus sequence could be repeated up to three times.

To assess whether the position of the ER was correlated with either visual or tactile extinction, we computed laterality scores based on the results of extinction tests. The procedure was similar to that used for Experiment 2, except that right- and left-sided correctly detected stimuli were used, respectively, as x_1 and as x_2 values.

5.2. Results and discussion

Results of visual and tactile extinction tests are reported in Table 2. Patients 9, 21 and 24, who did not detect any single left field stimulus, were considered to be affected by left hemianopia and excluded from the scoring for visual extinction, as well as patient 25, whose systematic attraction toward the right side stimulus prevented him from performing the double simultaneous stimulation task in the visual modality. Their respective ER position was of -1°, $+0.8^\circ$, -12° and $+9.6^\circ$. For patients with quadrantic field defect, only stimuli delivered in the intact quadrants are reported in Table 2 and were taken into account in the computation of the laterality score. Patient 9, who never detected any left side tactile stimulus, was excluded from the tactile extinction scoring.

Results showed a weak and nonsignificant correlation between the position of the ER and visual extinction ($r = 0.26$; $n = 21$; $z = 1.14$, $P > 0.2$). Unexpectedly, a significant *negative* correlation emerged between the position of the ER and tactile extinction ($r = -0.48$, $n = 24$; $z = -2.41$, $P < 0.05$). The subgroup of patients with extensive parietal lesion did not show any significant correlation between the ER position and either visual ($r = 0.14$) or tactile ($r = -0.11$) extinction.

No significant correlation was present between laterality scores for extinction in the two tested modalities ($r = 0.20$; $n = 21$; $z = 0.87$; $P > 0.3$). Visual extinction ($n = 21$) positively correlated with each of the cancellation tests (line: $r = 0.44$, $z = 1.98$, $P < 0.05$; letter: $r = 0.64$, $z = 3.22$, $P = 0.01$; bell: $r = 0.66$, $z = 3.17$, $P = 0.001$) and the landscape copy ($r = 0.68$, $z = 3.53$, $P < 0.001$). Tactile extinction ($n = 24$) positively correlated only with the landscape copy ($r = 0.42$, $z = 2.04$, $P < 0.05$).

These findings confirm the known relationship between extinction and neglect, although this relationship seems to be less close for tactile extinction than for visual extinction. To explain this difference, one could argue that it might reflect the basic distinction between personal and extrapersonal neglect [6], in that tactile extinction might be primarily related to personal neglect, whereas visuospatial tests, as well as the visual extinction test, are performed in the extrapersonal space.

The lack of significant positive correlation between extinction in either modality and the position of the ER appears to indicate that an ER deviation is not the basic mechanism of extinction. More puzzling is the finding of a negative correlation between the position of the ER and tactile extinction, which means that the more patients deviated rightward when pointing straight ahead, the less severe was left tactile extinction. This lack of positive correlation between ER deviation and tactile extinction suggests that the ER position is not a reliable predictor of forms of spatial bias which are more directly linked to body coordinates. This is even more striking if one considers that the somesthesic perceptual space should be coded in egocentric coordinates [59].

6. Experiment 4: directional motor bias

Left neglect patients may be reluctant to perform arm movements in or toward the left hemispace [5, 29, 45, 46, 57]. Although the role of this directional motor disorder in neglect is far from being clear [3], a distinction has been proposed between forms of neglect more linked to a 'perceptual' (or oculomotor) bias and forms of neglect more based on a deficit in executing arm movements toward the neglected space [8, 57].

The weak correlations between the position of the ER and the results of visuospatial tests that we observed in Experiment 2 could in principle reflect the possibility that our visuospatial battery was not apt at discriminating between these two factors, and that a deviation of the ER might essentially cause a spatial bias in goal-directed arm movements. It has indeed been proposed that the ipsilesional deviation of the ER in neglect determines a bias of motor behaviour in the same direction and to the same extent as the amplitude of the deviation [39]. Here we aimed at testing this version of the reference shift hypothesis by using the 'traffic light' paradigm [3], which consists of a reaction time (RT) test employing central visual stimuli arranged on the vertical midline of the computer screen (similar to a traffic light), and responses produced with the right hand and directed to the two lateral extremities of a computer keyboard. This paradigm was devised in order to study directional motor disorders in neglect while minimising lateralised perceptual aspects. It might be argued that the presence of lateralised sites of response acted as a confounding factor in the traffic light paradigm, by evoking problems in the perceptual encoding of the left sided response area in left neglect patients. If so, this paradigm would not be suitable to study directional motor disorders. However, results of a previous study [3] strongly suggest that this is not the case. In this study, conducted on a group of 34 RBD patients, principal components analysis demonstrated that impaired accuracy and slowed RTs for left-directed responses dissociated in different patients. While impaired accuracy loaded on the same factor as neglect tests, decreased speed of response loaded on a different factor, consistent with the idea that neglect patients were impaired in the initial selection of the left side response site, but not in producing the appropriate reaching movement in those trials in which a correct selection was accomplished. Indeed, inspection of individual data suggested that a directional motor disorder is rarely present in neglect patients, thus confirming the notion of a dissociation between 'motor' and 'perceptual' forms of neglect, with perceptual forms being more frequently observed than motor forms (see also [27, 48, 57]).

In view of these considerations, we [11] recently tested twelve RBD patients (six with left neglect signs and six without left neglect signs) on the proprioceptive straight-ahead task and the traffic light paradigm, and found no correlation between the position of the egocentric reference and the latencies to direct a motor response toward either side of space. Here we aimed at extending these results in a larger group of patients.

6.1. Procedure

Subjects sat in front of a computer monitor at a distance of approximately 50 cm. A paper board was placed on the computer keyboard, leaving three windows open on three different six-key areas: a right sided area, a middle area, and a left-sided area. Right- and left-side areas were at about 13 cm from the middle area. Three circles were presented in a vertical array on the midline of the screen (see [3] for details). After an interval of 2000 ms, one of the circles became grey (target). Upon the appearance of an upper target, subjects had to move their right hand from the home position at the centre of the keyboard to whatever key situated in the right-side area; when a middle target appeared, response keys were in the middle area; when a lower target occurred, subjects had to press a key on the left-side area. After every trial, subjects had to place again their hand at the home position. Response time was measured from target onset to key press. One block of twelve practice trials and ten blocks of four upper-, four middle-, and four lower target trials each were presented. The order of trials within a block was randomised. At the end of a test session, an inverted version of the motor task was performed (upper target → left-directed response, lower target → right-directed response). The response times for the two versions of the motor task were pooled, in order to minimise possible effects due to vertical neglect or stimulus-response compatibility. Only correct left- and right-directed responses ranging from 150 to 4500 ms were taken into account in the subsequent analysis.

In order to examine the relationships between the position of the ER and patients' performance on the traffic light paradigm, laterality scores were derived from each patient's percentage of accuracy and mean RTs for left- and right-directed responses. The procedure was similar to that used in Experiment 2, except that, for the accuracy score, the number of correct right-directed responses was used as x_1 value, and the number of correct left-directed responses was used as x_2 value. For response time, values for x_1 and x_2 were given by each patient's mean RT for, respectively, correct left-directed and right-directed responses.

6.2. Results and discussion

Table 4 reports individual results (accuracy and reaction times). No significant correlation was found between laterality scores of the RT test and any of the neglect tests (accuracy: $r = 0.06$ to 0.37; RT: $r = -0.09$ to 0.29; all *P*s n.s.). We thus confirmed previous results obtained with the traffic light paradigm [3], suggesting that distinct mechanisms operate in the determinism of a directional motor disorder and in producing signs of spatial neglect in traditional visuospatial testing.

Consistent with our results, Karnath, Dick and Konczak [40] found that RBD patients' accuracy and their kinematic trajectory when producing goal-directed movements are not affected by the presence of neglect; these authors concluded that exploratory and goal-directed movements might not share the same reference frame. Similarly, Perenin [50] failed to find evidence for an ipsilesional bias when she asked four patients with left neglect to point at visual targets with their right hand (two of the patients actually pointed leftward of the targets); an ipsilesional bias was instead present in four patients with optic ataxia.

We observed weak and statistically nonsignificant correlations between the ER position and the laterality scores for accuracy ($r = 0.06$; $z = 0.30$; $P > 0.7$) and response times ($r = 0.16$; $z = 0.75$, $P > 0.4$), thus indicating that speed and accuracy of lateralised motor responses cannot be predicted from the position of the ER. Nonsignificant correlations were also found when only patients with extensive parietal lesions were taken into account (accuracy: $r = -0.16$; RT: $r = 0.29$).

Thus, although both the pointing straight-ahead test and the traffic light paradigm involve movements performed with the right arm, no reliable correlation emerged between these tasks in our patient series. Some differences between the two tasks can help explain the observed low correlations. The straight-ahead pointing consists of movements executed without the aid of vision, without time constraint and with the possibility of autocorrections; the traffic light paradigm, by contrast, involves ballistic movements of reaching to a lateralised goal position, performed under visual control. Our findings are consistent with the notion that different functional mechanisms are employed for programming or

Table 4
Patients' performance on the traffic light paradigm (Experiment 4) and on the RT test to lateralised visual stimuli (Experiment 5)

Patient	Traffic light paradigm % left/right correct responses	Traffic light paradigm RT (ms) for left/right responses	Lateralised visual stimuli: % correct responses to left/right targets	Lateralised visual stimuli: RT (ms) to left/right targets
1	83/90	2483/2042	100/100	1092/1034
2	96/94	1969/1835	98/100	1542/1210
3	88/95	2585/2510	90/90	1126/1085
4	93/96	1468/1358	100/100	719/671
5	96/100	1280/1252	97/97	1217/579
6	96/95	1720/1768	100/100	789/599
7	86/90	1585/1513	100/100	712/552
8	86/93	1759/1162	100/100	893/730
9	79/88	2074/2008	95/98	2025/1267
10	76/69	2562/2583	100/100	926/621
11	94/94	2034/2249	100/98	1023/607
12	98/96	2103/1904	98/93	851/784
13	94/91	2401/2121	100/100	903/849
14	68/75	2326/2057	87/97	1437/1145
15	85/90	2762/2650	93/100	1606/1062
16	98/95	2093/2039	100/100	666/648
17	68/71	1956/1790	80/100	1995/895
18	96/95	1875/1889	97/90	1426/1208
19	90/96	1984/1728	73/98	1882/1010
20	70/79	2579/2312	75/73	1126/835
21	64/68	2588/2518	80/100	1631/763
22	64/78	2631/2321	55/98	1783/1052
23	90/91	2725/2382	88/100	1742/861
24	75/75	3313/3053	70/100	1467/668
25	35/35	3403/2766	75/93	2263/1434

executing these two types of arm movements, and seem to rule out the role of an egocentric frame as a common reference for performing the two tasks. Accessorily, the present results rule out the possibility that a directional motor disorder influenced performance on the proprioceptive pointing task. If this were the case, such a directional impairment would have equally affected the motor output stage independent of the input modality (visual or proprioceptive); consequently, the pointing task and the traffic light paradigm would have given comparable results, which was not the case.

7. Experiment 5: subclinical spatial bias

The data presented thus far strongly suggest that there is no causal relationship between deviation of the egocentric reference and clinical signs of neglect (Experiment 2) or extinction (Experiment 3), nor between the position of the ER and a directional motor bias for goal-directed arm movements (Experiment 4). However, the possibility remains open that a deviation of the ER might determine a form of spatial bias which is not necessarily accompanied by signs of neglect, extinction, or directional motor disorder. We have recently demonstrated that RBD patients without neglect may show a deviation of their egocentric reference [10]. On the other hand, it has repeatedly been shown that RBD patients without clinically manifest neglect may nevertheless suffer from subtler forms of spatial bias. For example, when pressing a central key in response to lateralised visual targets, these patients may be slower with left side than with right side targets [2, 3]. This phenomenon may occur even in the absence of visual extinction (see [2] cases R3 and R4). Because these forms of spatial bias may not be apparent in conventional visuospatial testing, the visuospatial battery that we used to screen for neglect in the present study might not have been sensitive enough to disclose these signs. In Experiment 5 we investigate the relationship between such a subclinical spatial bias and the position of the ER.

7.1. Procedure

Subjects sat in front of a computer monitor at a distance of approximately 50 cm. Three horizontally arranged black circles were displayed, the central circle being located at the centre of the screen. Distance between circles was 23 mm. Subjects were instructed to maintain fixation on the central circle. Eye position was monitored during the practice trials, and subjects were given appropriate feedback. After an interval of 2000 ms, one of the circles became grey (target). When a right- or a left-side target appeared, subjects, who maintained the index finger of their right hand on the centre of the computer spacebar, had to respond by pressing the spacebar as quickly as possible. Subjects had to refrain from responding when the middle circle became grey (*catch trials*). Response time was measured from target onset to key press. The target disappeared when a response was made or after 5000 ms. One block of six practice trials and ten blocks of four right- and four left-sided trials each were presented. The order of trials within a block was randomised. Only responses ranging from 150 to 4500 ms were taken into account in the subsequent analysis.

Laterality scores were obtained from patients' accuracy and RT performance following the procedure detailed in Experiment 2, except that, for accuracy scores, the number of right- and left-sided correct responses served, respectively, as x_1 and x_2; for response time scores, mean RTs to right and left targets were used, respectively, for x_1 and x_2 values.

7.2. Results and discussion

Patients' accuracy and mean response times are shown in Table 4. Accuracy and RTs positively correlated with each other ($r = 0.61$; $z = 3.33$; $P < 0.001$), indicating that patients made more omissions and produced longer RTs when responding to left side stimuli than when responding to right side stimuli. Laterality scores for RTs were positively correlated with scores for letter cancellation ($r = 0.41$; $z = 2.06$; $P < 0.05$), line bisection ($r = 0.49$; $z = 2.51$; $P < 0.05$), and landscape drawing ($r = 0.64$; $z = 3.59$; $P < 0.001$). Positive correlations also emerged between the RT task, in terms of both accuracy and RTs, and several neglect tests. A previous study using the same RT paradigm in a different group of RBD patients [3] indicated an analogous relationship between this paradigm and neglect tests, thereby suggesting that the same form of spatial bias influenced patients' performance on all these tasks.

By contrast, no significant correlation emerged between the position of the ER and laterality scores for accuracy ($r = 0.09$; $z = 0.44$; $P > 0.6$) or RTs ($r = 0.04$; $z = 0.20$; $P > 0.8$). Nonsignificant correlations were also obtained by taking into account only patients with extensive parietal lesion (accuracy: $r = 0.02$; response times: $r = -0.46$). Thus, patients apparently located their subjective body midline by using different mechanisms from those at work when they manually responded to lateralised visual stimuli.

8. General discussion

In the present study, we assessed the position of the egocentric frame of reference in a group of unselected right brain-damaged patients (Experiment 1). Consistent with earlier observations [28], we found an overall rightward shift of the perceived midline only in the subgroup of patients with extensive parietal lesions. We subsequently investigated the relationships between the position of the egocentric frame of reference and several measures of spatial bias. We found that the direction and magnitude of the deviation of the ER is neither positively related to performance on neglect tests (Experiment 2), nor to clinical measures of extinction (Experiment 3), nor to performance on a RT task involving lateralised arm movements (Experiment 4), nor, finally, to performance on a RT task devised to detect subtle forms of spatial bias (Experiment 5).

Results of Experiments 2–5 bring into question the main tenet of the reference shift hypothesis, that is, that a direct causal relationship exists between ipsilesional deviation of the ER and ipsilesional bias in RBD patients' spatially-related behaviour. Our findings rather suggest that an ipsilesional ER shift may follow parietal lesions, but it is not necessarily associated with the behavioural consequences of these lesions. This hypothesis is consistent with the findings of Hasselbach and Butter [28], that an ipsilesional deviation of the ER (as tested by a visual midline localisation test) was present in two RBD patients with extensive parietal damage, but not in three RBD patients without extensive parietal damage, all patients showing signs of left neglect on a cancellation test. Perenin [50], who studied the ER position in 25 left neglect patients, found no evidence of rightward ER shift in three patients; fifteen other left neglect patients deviated toward the right side on two tasks of subjective body orientation (visual and nonvisual); the ten remaining patients deviated ipsilesionally in only one of the two tasks. More critically, also eight parietally-lesioned patients who showed signs of optic ataxia, but no sign of neglect, all deviated ipsilesionally on these tasks (five on both tasks, three on only one). This evidence, together with our results, challenges the reference shift hypothesis of neglect, which seems unable to specify the mechanisms by which an ipsilesional ER shift may be associated with neglect in some cases, with optic ataxia in others, or with no spatial bias at all in still other patients (see case 6 in [10] and cases 3 and 6 in the present study).

Our results suggest that other mechanisms than an ipsilesional ER shift must be at work in determining RBD patients' rightward bias in spatially-oriented behaviour. Although a contribution of an ER shift to spatial bias is still possible on the basis of our results (and even plausible, on account of the association between ER shift and parietal lesions observed in Experiment 1), several examples of double dissociation emerged in Experiments 2–5, thus suggesting that this contribution is by no means crucial. For example, some of our patients presented a leftward deviation of the forward projection of their subjective body midline, yet they showed left neglect signs in cancellation and bisection tests (see, e.g., patients 16, 20 and 24), thus confirming our previous observation in a different patient (case 2 in [10]). This possibility is further strengthened by our finding of weak correlations between laterality scores in visuospatial tasks and ER position also in patients with extensive parietal lesions. Another possible explanation of the present findings is that an ER deviation is a consequence, and not a cause, of spatial bias induced by right hemisphere lesions [10]. If so, signs of spatial bias and ER shift are indeed expected to occasionally dissociate, just as different signs of spatial bias may dissociate among each other in RBD patients.

Much of the recent emphasis on the relationship between ER shift and neglect derived from the observation of a temporary remission of neglect signs during several experimental manoeuvres known to affect the position of the ER. Thus, a decrease of left neglect signs has been observed during various sensory stimulations (vestibular caloric stimulation neck-proprioceptive vibration, optokinetic stimulation, transcutaneous electrical stimulation: see [6] for review), as well as during leftward trunk rotation [13, 42]. The reference shift hypothesis maintains that these manoeuvres act by directly correcting the rightward distortion of spatial representation which results in neglect. However, results inconsistent with this assumption were obtained by Bisiach et al. [7], who found that leftward optokinetic stimulation *increased* the leftward error made by left neglect patients when they placed the left endpoint of an imaginary horizontal line whose midpoint was given. Bisiach et al. concluded that optokinetic stimulation may temporarily remove neglect signs without acting on the underlying disorder.

From another point of view, Gainotti [19] proposed that the improvement in neglect symptoms observed after vestibular or optokinetic stimulation was due to an increase in selective attention to the contralesional parts of body and space. This mechanism is related to the facilitation of contralesionally-directed eye movements, which not only allows better exploration of the neglected half-space, but also automatically orients attention toward this space, because an eye movement usually shifts the focus of attention in its direction [54]. In support of this view, slow movement of a random-dot background towards the left was found to improve left neglect even in the absence of optokinetic nystagmus [44]. Note that a gaze shift need not be the only mechanism at work; "[o]ther components of the orienting reaction, such as head turning and trunk turning, are probably part of the same phenomenon, namely an automatic movement of attention towards the part of space pointed at by the body-orienting apparatus" [19, p. 117].

Thus, there is no consensus about the mechanisms by which these experimental manoeuvres reduce neglect signs. On the one hand, stimulations are deemed to act on the central mechanisms of neglect; on the other hand they are believed to mitigate neglect by merely circumventing its manifestations. Our demonstration that patients with left neglect may not show a rightward ER shift provides a possibility of testing these alternative hypotheses. According to the reference shift hypothesis, these patients should be exceptional in that their neglect is not caused by an ER deviation; consequently, experimental stimulations should be of no effect on their neglect. By contrast, according to the alternative hypothesis, these manoeuvres should decrease neglect also in these patients, because they engender a contralesional attentional shift [19], independent of the ER position.

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References

[1] Albert ML. A simple test of visual neglect. Neurology 1973;23:658–64.
[2] Bartolomeo P. The novelty effect in recovered hemineglect. Cortex 1997;33:323–32.
[3] Bartolomeo P, D'Erme P, Perri R, Gainotti G. Perception and action in hemispatial neglect. Neuropsychologia 1998;36:227–37.
[4] Bisiach E. Extinction and neglect: Same or different? In: Paillard J, editor. Brain and space. Oxford: Oxford University Press, 1991: 251–7.
[5] Bisiach E, Geminiani G, Berti A, Rusconi ML. Perceptual and premotor factors of unilateral neglect. Neurology 1990;40:1278–81.
[6] Bisiach E, Perani D, Vallar G, Berti A. Unilateral neglect: Personal and extra-personal. Neuropsychologia 1986;24:759–67.
[7] Bisiach E, Pizzamiglio L, Nico D, Antonucci G. Beyond unilateral neglect. Brain 1996;119:851–7.
[8] Bisiach E, Tegnér R, Làdavas E, Rusconi ML, Mijovic′ D, Hjaltason H. Dissociation of ophtalmokinetic and melokinetic attention in unilateral neglect. Cerebral Cortex 1995;5:439–47.
[9] Brodie EE, Pettigrew LE. Is left always right? Directional deviations in visual line bisection as a function of hand and initial scanning direction. Neuropsychologia 1996;34:467–70.
[10] Chokron S, Bartolomeo P. Patterns of dissociation between left hemineglect and deviation of the egocentric reference. Neuropsychologia 1997;35:1503–8.
[11] Chokron S, Bartolomeo P. Position of the egocentric reference and directional arm movements in right brain-damaged patients. Brain and Cognition 1998;37:405-18.
[12] Chokron S, Bartolomeo P, Perenin MT, Helft G, Imbert M. Scanning direction and line bisection: a study of normal subjects and unilateral neglect patients with opposite reading habits. Cognitive Brain Research 1998;7:173–8.
[13] Chokron S, Imbert M. Variations of the egocentric reference among normal subjects and a patient with unilateral neglect. Neuropsychologia 1995;33:703–11.
[14] Chokron S, Perenin MT, Imbert M. Scanning direction and line bisection. Perception 1993;22:120.
[15] D'Erme P, De Bonis C, Gainotti G. Influenza dell'emi-inattenzione e dell'emianopsia sui compiti di bisezione di linee nei pazienti cerebrolesi. Archivio di Psicologia, Neurologia e Psichiatria 1987; 48:165–89.
[16] Dellatolas G, De Agostini M, Jallon P, Poncet M, Rey M, Lellouch J. Mesure de la préférence manuelle par autoquestionnaire dans la population française adulte. Revue de Psychologie Appliquée 1988;38:117–36.
[17] De Pellegrino G, De Renzi E. An experimental investigation on the nature of extinction. Neuropsychologia 1995;33:153–70.
[18] Farnè A, Ponti F, Làdavas E. In search for biased egocentric reference frames in neglect. Neuropsychologia 1998;36:611–23.
[19] Gainotti G. The role of spontaneous eye movements in orienting attention and in unilateral neglect. In: Robertson IH, Marshall, JC, editors. Clinical and experimental studies. Hove (U.K.): Lawrence Erlbaum Associates, 1993:107–22.
[20] Gainotti G, D'Erme P, Bartolomeo P. Early orientation of attention toward the half space ipsilateral to the lesion in patients with unilateral brain damage. Journal of Neurology, Neurosurgery and Psychiatry 1991;54:1082–9.
[21] Gainotti G, D'Erme P, Monteleone D, Silveri MC. Mechanisms of unilateral spatial neglect in relation to laterality of cerebral lesions. Brain 1986;109:599–612.
[22] Gauthier L, Dehaut F, Joanette Y. The bells test: A quantitative and qualitative test for visual neglect. International Journal of Clinical Neuropsychology 1989;11:49–53.
[23] Goodrich SJ, Ward R. Anti-extinction following unilateral parietal damage. Cognitive Neuropsychology 1997;14:595–612.
[24] Gras P, Virat-Brassaud ME, Graule A, André N, Giroud M, Dumas R. Activation fonctionnelle hémisphere et référence égocentrique. Revue Neurologique 1993;149:347–50.
[25] Halligan P, Marshall JC, editors. Spatial neglect: position papers on theory and practice. Neuropsyschological Rehabilitation 1994;4:99–240.
[26] Halligan P, Marshall JC, Wade DT. Visuospatial neglect: Underlying factors and test sensitivity. Lancet 1989;334:908–12.
[27] Harvey M, Milner AD, Roberts RC. An investigation of hemispatial neglect using the landmark test. Brain and Cognition 1995;27:59–78.
[28] Hasselbach M, Butter CM. Ipsilesional displacement of egocentric midline in neglect patients with, but not in those without, extensive right parietal damage. In: Thier P, Karnath HO, editors. Parietal lobe contributions to orientation in 3D-space. Heidelberg: Springer-Verlag, 1997:579–95.
[29] Heilman KM, Bowers D, Coslett HB, Whelan H, Watson RT. Directional hypokinesia: prolonged reaction times for leftward movements in patients with right hemisphere lesions and neglect. Neurology 1985;35:855–9.
[30] Heilman KM, Bowers D, Watson RT. Performance on hemispatial pointing task by patients with neglect syndrome. Neurology 1983;33:661–4.
[31] Jeannerod M, Biguer B. The directional coding of reaching movements. A visuomotor conception of visuospatial neglect. In: Jeannerod M, editor. Neurophysiological and neuropsychological aspects of spatial neglect. Amsterdam: Elsevier Science Publishers, 1987:87–113.
[32] Jeannerod M, Biguer B. Référence égocentrique et espace représenté. Revue Neurologique 1989;145:365–9.
[33] Kaplan RF, Cohen RA, Rosengart A, Elsner AE, Hedges TR, Caplan LR. Extinction during time controlled direct retinal stimulation after recovery from right hemispheric stroke. Journal of Neurology, Neurosurgery and Psychiatry 1995;59:534–6.
[34] Karnath H-O. Deficits of attention in acute and recovered hemineglect. Neuropsychologia 1988;20:27–45.

[35] Karnath H-O. Disturbed coordinate transformation in the neural representation of space as the crucial mechanism leading to neglect. Neuropsychological Rehabilitation 1994;4:147–50.
[36] Karnath H-O. Subjective body orientation in neglect and the interactive contribution of neck muscle proprioception and vestibular stimulation. Brain 1994;17:1001–12.
[37] Karnath H-O. Transcutaneous electrical stimulation and vibration of neck muscles in neglect. Experimental Brain Research 1995;105:321–4.
[38] Karnath H-O. Optokinetic stimulation influences the disturbed perception of body orientation in spatial neglect. Journal of Neurology, Neurosurgery and Psychiatry 1996;60:217–20.
[39] Karnath H-O. Neural encoding of space in egocentric coordinates? Evidence for and limits of a hypothesis derived from patients with parietal lesions and neglect. In: Thier P, Karnath H-O, editors. Parietal lobe contributions to orientation in 3D space. Heidelberg: Springer-Verlag, 1997:497–520.
[40] Karnath H-O, Dick H, Konczak J. Kinematics of goal-directed arm movements in neglect: control of hand in space. Neuropsychologia 1997;35:435–44.
[41] Karnath H-O, Fetter M. Ocular space exploration in the dark and its relation to subjective and objective body orientation in neglect patients with parietal lesions.Neuropsychologia 1995;33:371–7.
[42] Karnath H-O, Schenkel P, Fischer B. Trunk orientation as the determining factor of the contralateral deficit in the neglect syndrome and as the physical anchor of the internal representation of body orientation in space. Brain 1991;114:1997–2014.
[43] Mark VW, Heilman KM. Bodily neglect and orientational biases in unilateral neglect syndrome and normal subjects. Neurology 1990;40:640–3.
[44] Mattingley JB, Bradshaw JL, Bradshaw JA. Horizontal visual motion modulates focal attention in left unilateral spatial neglect. Journal of Neurology, Neurosurgery and Psychiatry 1994;57:1228–35.
[45] Mattingley JB, Bradshaw JL, Phillips JG. Impairments of movement initiation and execution in unilateral neglect. Brain 1992;115:1849–74.
[46] Mesulam M-M. A cortical network for directed attention and unilateral neglect. Annals of Neurology 1981;10:309–25.
[47] Mesulam MM. Attention, confusional states and neglect. In: Mesulam MM, Davis FA, editors. Principles of behavioral neurology. Philadelphia (PA), 1985:125–68.
[48] Mijović D. Mechanisms of visual spatial neglect: absence of directional hypokinesia in spatial exploration. Brain 1991;114:1575–93.
[49] Perenin MT. Référence égocentrique et cortex pariétal postérieur. Revue oto-neuro-ophtalmique 1992;16:14–6.
[50] Perenin MT. Optic ataxia and unilateral neglect: Clinical evidence for dissociable spatial functions in posterior parietal cortex. In: Thier P, Karnath HO, editors. Parietal lobe contributions to orientation in 3D-space. Heidelberg: Springer-Verlag, 1997:289–308.
[51] Reuter-Lorenz PA, Posner MI. Components of neglect from right-hemisphere damage: an analysis of line bisection. Neuropsychologia 1990;28:327–33.
[52] Rossetti Y, Rode G, Pisella L, Farnè A, Li L, Boisson D, Perenin MT. Prism adaptation to a rightward optical deviation rehabilitates left hemispatial neglect. Nature 1998;395:166–9.
[53] Shallice T, Burgess P. The domain of supervisory processes and temporal organization of behaviour. Philosophical Transactions of the Royal Society of London B 1996;351:1405–12.
[54] Shepherd M, Findlay JM, Hockey RJ. The relationship between eye movements and spatial attention. The Quarterly Journal of Experimental Psychology 1986;38A:475–791.
[55] Stein BA, Wallace MT, Meredith MA. Neural mechanisms mediating attention and orientation to multisensory cues. In: Gazzaniga MS, editor. The cognitive neurosciences. Cambridge, MA: The MIT Press, 1994:683–702.
[56] Stein JF. The representation of egocentric space in the posterior parietal cortex. Behavioral and Brain Sciences 1992;15:691–700.
[57] Tegnér R, Levander M. Through a looking glass. A new technique to demonstrate directional hypokinesia in unilateral neglect. Brain 1991;114:1943–51.
[58] Vallar G, Antonucci G, Guariglia C, Pizzamiglio L. Deficits of position sense, unilateral neglect and optokinetic stimulation. Neuropsychologia 1993;31:1191–200.
[59] Vallar G, Bottini G, Rusconi ML, Sterzi R. Exploring somatosensory neglect by vestibular stimulation. Brain 1993;116:71–86.
[60] Vallar G, Guariglia C, Rusconi ML. Modulation of the neglect syndrome by sensory stimulation. In: Thier P, Karnath H-O, editors. Parietal lobe contributions to orientation in 3D-space. Heidelberg: Springer-Verlag, 1997:555–78.
[61] Vallar G, Rusconi ML, Bignamini L, Germiniani G, Perani D. Anatomical correlates of visual and tactile extinction in humans: a clinical CT scan correlation study in man. Journal of Neurology, Neurosurgery and Psychiatry 1994;57:464–70.
[62] Ventre J, Flandrin JM, Jeannerod M. In search for the egocentric reference. A neuropsychological hypothesis. Neuropsychologia 1984;22:797–806.
[63] Werner H, Wapner S, Bruell JH. Experiments on sensory-tonic field theory of perception: VI. effect of position of head, eyes and of object on position of the apparent median plane. Journal of Experimental Psychology 1953;46:293–9.