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RESEARCH ARTICLE

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Gravitational influences on reference frames for mapping somatic stimuli in brain-damaged patients

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Abstract Previous studies have shown that the manipulation of body position in space can modulate the manifestations of visual neglect. Here, we investigated in right brain-damaged patients (RBD) the possible influence of gravitational inputs on the capability to detect tactile stimuli delivered to hands positioned in ipsilesional or contralesional space. RBD patients (with or without impairments in detecting contralesional stimuli under single and double stimulation conditions) and healthy control subjects were tested in a tactile detection task in which gravitational (upright vs. supine) and hand position (anatomical vs. crossed) variables were orthogonally varied. The postural manipulation of the entire body turned out to influence the degree of tactile detection. In particular, RBD patients with tactile deficits detected a significantly higher number of left-sided stimuli in the supine posture than in the upright posture. Moreover, crossing of hands improved the ability of RBD patients with tactile deficits in detecting stimuli delivered to their left contralesional hand. The beneficial effect of lying supine was independent of the spatial position of the hands, thus suggesting that the improvement of performance dependent upon entire-body posture and that dependent upon crossing hands may rely upon separate mechanisms.

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Introduction

A failure to report somatic stimuli delivered to the contralesional body parts, is a frequent occurrence following unilateral brain lesions. Theoretically, at least two different mechanisms may account for this impairment. First, a cerebral lesion centred upon the primary somatosensory areas may lead to a hemianaesthesia, a pure sensory deficit due to the disruption of low-level information processing concerning the analysis of primary sensory attributes (e.g. numerosity, sharpness, roughness and temperature). Second, a cerebral lesion encroaching upon the associative areas of the inferior parietal lobule may lead to tactile neglect, a cognitive deficit consisting in the disruption of the sophisticated neural machinery for orienting attention towards the stimulated body part and integrating information about stimuli onto the egocentric representation of the body.

Strictly related to neglect is the phenomenon of tactile extinction, according to which brain-damaged patients may detect a tactile stimulus delivered alone to the contralesional part of the body, but ignore the same stimulus when presented simultaneously with an identical, ipsilesional stimulus (Bisiach and Vallar 1988). Neglect and extinction are particularly frequent after lesions centred upon the right hemisphere (Schwartz et al. 1979; Gainotti et al. 1989) so that, in most of the right brain-damaged (RBD) patients, sensory and cognitive components coexist; thus, it is not easy, at least on purely clinical grounds, to disentangle the relative influence of hemianaesthesia and neglect (or extinction) on the difficulty in reporting somatic stimuli shown by these patients.

Several studies provide support to the notion that deficits classically related to hemianaesthesia, may be due, at least partially, to tactile neglect. Vallar et al. (1990, 1993) first reported a temporary remission of haemianaesthesia after vestibular stimulation, demonstrating that orienting attention toward the contralesional side can compensate for the sensory deficit. In this vein, studying a group of RBD ''extinguent'' patients, Aglioti et al. (1998) have shown that an increase in the salience of the stimulus delivered to the contralesional hand can reduce the degree of tactile extinction. Analogously, Olson et al. (2003) demonstrated that increasing the salience of the left, contralesional stimuli, improved the left-sided tactile awareness of an RBD patient with tactile extinction.

The pattern of tactile extinction can also be modulated by manipulating different representations of space, each of which refer to different frames of reference. Moscovitch and Behrmann (1994) studied a group of 11 RBD patients with neglect by delivering somatic stimuli to the ulnar and the radial side of the wrist in both the palm up and the palm down position. Patients omitted contralesional stimuli independent of the palm orientation, suggesting that somatic stimuli are coded not only with respect to a sensory, somatotopic frame of reference but also with respect to a higher order frame of reference. Tinazzi et al. (2000) provided evidence that tactile extinction may be present not only when stimuli are delivered to the two sides of the body, but also when they are delivered to a single hand or finger, demonstrating that tactile stimuli may be coded as left or right with respect to multiple egocentric frames of reference dynamically scaled from the corporeal midline to other parts of the body. In a series of two studies, Aglioti et al. confirmed that the manipulation of both somatotopic coordinates and of different body-centred frames of reference may influence the capability of RBD patients with neglect and/or extinction to report simple somatic stimuli. Smania and Aglioti (1995) asked RBD patients to report somatic stimuli delivered to the left, to the right, or simultaneously to both hands, under two experimental conditions. In the anatomical condition, each hand was in its homonymous hemispace; in the crossed condition, each hand crossed the corporeal midline over the other. Controls and RBD patients without tactile extinction or neglect performed better when the hands were in the anatomical position than in the crossed position. In contrast, RBD patients with signs of tactile extinction or neglect, detected stimuli delivered to their contralesional hand with higher accuracy in the crossed position than in the anatomical position. In a further study on a larger sample of patients, Aglioti et al. (1999) demonstrated that the increase in accuracy of the contralesional hand in the crossed condition was also found when the hands were crossed within both the left and right hemispace, clearly suggesting that the beneficial effect of crossing the hands is not only linked to the corporeal midline, but it also depends on the position of the hands with respect to each other. A corollary observation from that study claims that the magnitude of the effect of crossing the hands is positively correlated with the presence and the severity of tactile extinction and personal neglect, but not of visuospatial neglect (Aglioti et al. 1999). Moreover, the clear amelioration in detecting tactile stimuli contingent upon crossing hands occurs in the absence of changes of disownership of the contralesional upper limb (Moro et al. 2004).

Although some studies point out at the possible inconsistency of the crossing effect (Vaishnavi et al. 2000, 2001), a study of 24 RBD patients with left tactile extinction supports the notion that crossing upper limbs influences detection of tactile stimuli (Bartolomeo et al. 2004). These authors found that crossing the limbs caused only a mild improvement in the accuracy in detecting left, contralesional stimuli, but a clear deterioration of performance for stimuli delivered to right body parts. It is also interesting that, in keeping with Aglioti et al. (1999), the severity of left visuospatial neglect did not correlate with changes of performance contingent upon limb crossing (Bartolomeo et al. 2004).

Previous studies suggest that the manipulation of body posture in space can modulate the phenomenology of visual neglect (e.g. Làdavas 1987; Calvanio et al. 1987; Karnath et al. 1991, 1993). Moreover, the specific influence of gravitational inputs on visuospatial neglect has been examined in two studies in which neglect patients were tested in both upright and supine position (Pizzamiglio et al. 1995, 1997). These authors found that the reduction of gravitational inputs, obtained by placing subjects in supine position, ameliorates the performance of neglect patients in a visual line bisection task (Pizzamiglio et al. 1995, 1997). However, a study of neglect patients' exploratory movements in darkness shows that changes of gravitational inputs did not bring about any modulation of the exploration bias of these patients (Karnath et al. 1998).

In any case, neither the possible influence of gravity on modulation of tactile extinction nor the possible interaction of gravitational inputs with spatial changes of body parts has been explored hitherto. Here, we addressed these issues by testing RBD patients (with or without signs of tactile extinction) and healthy control subjects in a tactile detection task in which gravitational and hand position variables were orthogonally varied. More specifically, subjects performed a standard tactile extinction test with hands either in the anatomical or in the crossed position and in two different gravitational conditions namely upright or supine. This procedure allowed us to explore: (1) whether the influence of gravitational inputs induces a change in the rate of extinction of left-sided tactile stimuli; (2) whether crossing the hands induces a reduction of left-sided tactile extinction; (3) whether such a beneficial effect is different in upright and supine positions.

Materials and methods

Subjects

Eighteen consecutive RBD patients recruited from the Neurorehabilitation Unit, at the Ospedale Sacro Cuore, (Negrar, Vr, Italy) over a 37-month period gave their informed consent to participate in the study. The procedures were approved by the local ethics committee and the study was carried out in accordance with the guidelines of the Declaration of Helsinki. All patients were right-handed according to the Briggs and Nebes (1975) laterality inventory. No patient showed signs or symptoms of widespread mental deterioration on the MMSE (Folstein et al. 1975). For each patient, the site of the lesion was documented by means of radiological (CT or MRI) exams. Additional clinical and radiological information for each patient is provided in Table 1.

Twelve healthy right-handed subjects (six women and six men, mean age 67.8 years, S.D. = 4.9, range = 60–76; mean education = 12.3 years, S.D. = 5.3, range = 5–19), served as controls. The presence of visuospatial neglect was preliminarily ascertained in each patient by means of a series of cancellation, drawing, reading and writing tests, and by examining the orientational bias towards the ipsilesional hemispace (Peru et al. 1996, 1997). Visual extinction was assessed by a standard confrontation technique (Bisiach et al. 1986) in which the examiner simultaneously wiggled his/her index fingertips in the left or in the right visual hemifield or in both hemifields. A pre-fixed, pseudo-random sequence of 10 unilateral finger twitches in either visual hemifield and 20 bilateral finger twitches, was delivered. Patients who missed more than 30% of contralesional stimuli during simultaneous double stimulation but detected at least 70% of left-sided stimuli in single stimulation conditions, were considered as affected by visual extinction. The presence of tactile extinction (TE) was ascertained as follows: each patient was seated in front of the examiner with the palms in contact with the plane of a table and with their corporeal midline aligned with the centre of the table. By using his second fingertips, the examiner delivered light and brief (about 0.5 s) touches to the dorsal surface of the patient's left or right hand, or both at the same time.

Patients, previously informed that stimuli could be single or double, were requested to report verbally if the left, the right, or both hands were stimulated. Subjects were blindfolded throughout the testing sessions. The comprehension of the instructions was checked by giving a few practice trials while subjects kept their eyes open.

The same pseudo-random sequence of 40 stimuli (20 unilateral–10 left and 10 right–and 20 bilateral) used for vision, was delivered. According to their performance in the preliminary test, patients were divided into two groups (see Table 1).

Group 1. As seen in controls, six (three men and three women, subject nos. 1–6) out of 18 RBD patients detected all the stimuli delivered under single stimulation condition, and missed no more than 15% of the stimuli delivered to their contralesional hand under double simultaneous stimulation condition. Thus, they were considered as "non-extinguent", and labelled as TE-. No patient from this group showed signs of visual extinction or visuospatial neglect.

Group 2. The remaining 12 RBD patients (ten men, and two women, subject nos. 7–18) omitted the stimuli delivered to their left, contralesional hand under double simultaneous stimulation condition, in at least 50% of the cases (see Table 1). Four out of the 12 subjects (nos. 7, 9, 10 and 11) detected contralesional stimuli in at least 80% of the trials. These subjects would correspond to

Table 1 Vintage of the RBD group

	Clinical and radiological data			Tests for assessing visuospatial neglect								
				Drawing							Hits	
No.	Gender	Age	Lesion Site	Albert	Reading	Copy	Memory	Writing	Bias	V.E.	single %	double %
1	F	50	F	–	–	–	–	–	–	–	100	100
2	M	61	Cs	–	–	–	–	–	–	–	100	90
3	F	74	Cs - bg	–	–	–	–	–	–	–	100	85
4	F	59	Bg	–	–	–	–	–	–	–	100	100
5	M	63	Bg	–	–	–	–	–	–	–	100	90
6	M	76	P	–	–	–	–	–	–	–	100	100
7	F	59	Bg	–	–	+	NP	+	+	+	80	50
8	M	66	P – O	–	–	NP	–	–	–	–	60	0
9	M	49	T - P - bg		–	NP	–	–	–	+	100	5
10	M	62	bg - caps	–	–	–	–	NP	–	–	100	35
11	M	87	F - P	–	–	–	–	–	–	–	80	0
12	M	76	F - T	–	–	–	–	–	–	–	50	0
13	M	75	Caps - thal	–	–	–	–	–	–	–	20	20
14	M	66	F – P - bg	–	–	NP	–	NP	–	+	0	0
15	M	63	Bg	–	NP		+	NP	+	+	10	0
16	M	62	F - P	+	+	–	–	–	–	+	0	0
17	F	80	P - O	+	+	–	–	NP	–	+	20	0
18	M	58	F – P - bg	–	–	–	–	–	–	–	0	0

Albert Albert cancellation test, *Bias* orientational bias, *V.E.* visual extinction, *Hits* % of correct detections of stimuli delivered to the left hand on the preliminary test for assessing tactile extinction, *R+* indicates an impaired performance, *R–* indicates a normal performance, *NP* indicates that test was not performed. *F* frontal, *P* parietal, *T* temporal, *O* occipital, *caps* internal capsule, *bg* basal ganglia, *cs* centrum semioval, *thal* thalamus the classical clinical definition of tactile extinction. The remaining eight subjects (nos. 8, 12, 13, 14, 15, 16, 17 and 18) omitted left-sided stimuli also in at least 40% of single trials. This, may in principle, suggest that these patients may suffer from primary somatic deficit. Previous studies, however, indicate that at least in RBD patients, even omission of a single contralesional tactile stimulus may be due to deficits of higher order attentional functions (Vallar et al. 1993; Smania and Aglioti 1995; Aglioti et al. 1999). On account of this, patients from this mixed group were labelled as tactile extinction plus (TE+) patients. Seven patients (nos. 7, 9,10,14,15,16 and 17) from this group showed signs of visual extinction, and four of them (nos. 7,15,16 and 17) also showed signs of visuospatial neglect.

Procedure

Unilateral and bilateral light and brief (about 0.5 s) touches to the dorsal surface of the subjects' hands were delivered by an examiner through his index fingertips. It is important to note that the experimenter who delivered the stimuli was blind as to the experimental hypothesis. Subjects were tested in four experimental blocks, differing in the subjects' body posture and hands spatial position. Body posture could be upright (subjects seated in front of the examiner) or supine (subjects were lying on a bed). The spatial position of hands could be anatomical (each hand located in its homonymous hemispace, i.e., the right hand in the right hemispace and the left hand in the left hemispace) or crossed (each hand was located in its heteronymous hemispace, i.e. the right hand in the left hemispace and the left hand in the right hemispace). For patients' comfort, the ipsilesional limb was always crossed over the contralesional limb, whereas in the case of healthy subjects who served as controls, half of them crossed the left over the right limb, and the remaining half did the opposite. The order of the different experimental blocks was systematically varied across subjects. Figurines representing the subjects' body posture and hand positions in each of the four experimental blocks are shown in Fig. 1.

In each of the four blocks (upright anatomical, upright crossed, supine anatomical and supine crossed), 10 single left, 10 single right and 20 double simultaneous stimuli were delivered according to a random (and fixed) sequence. On each trial, subjects were requested to verbally report, while blindfolded, the side of stimulation (left, right, or bilateral). Correct detections scored 1 point and omissions scored 0 points.

Results

Detection of left-sided stimuli in RBD patients

Percent correct detections of left-sided stimuli in the two groups of patients in the different experimental conditions are shown in Fig. 2.

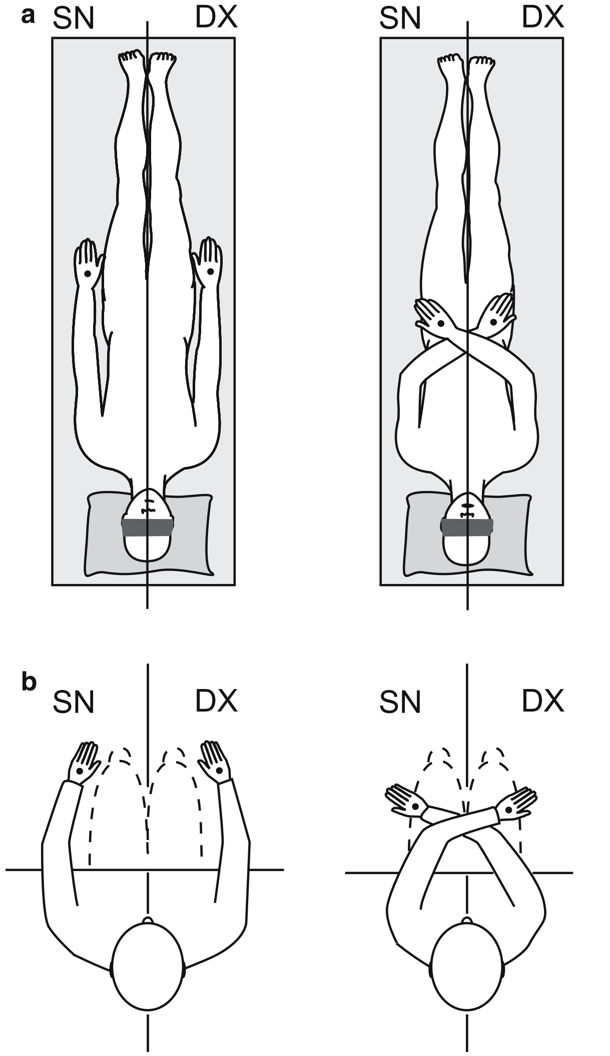

Fig. 1 Schematic representations under different testing conditions. Legend: **a** supine posture: left panel: hands in anatomical position; right panel: hands in crossed position; **b** upright posture: left panel: hands in anatomical position; right panel: hands in crossed position

To avoid possible violations of normality, arcsin transform data instead of percentage values were entered in a mixed model ANOVA where the Group (TE+ vs. TE-) was the between-subjects factor; and the Number of Stimuli (single vs. double), the Position of the Hands with respect to the midline (anatomical vs. crossed) and the Posture of the Body (upright vs. supine) were the within-subject factors.

The factor Group was highly significant [$F(1,16)=83.49$, $p<0.0001$] because correct detections of left-sided stimuli were 98.2% in TE- and 42.6% in TE+ patients. The factor Number of Stimuli turned out to be highly significant [$F(1,16)=54.94$, $p<0.0001$] insofar as more stimuli were detected under single stimulus condition (84.5%) than the double (56.3%) stimuli condition. This effect is entirely due to the TE+ group as indicated by the significance of the Group x Number of Stimuli interaction [$F(1,16)=26.25$, $p<0.0001$] and the post-hoc comparisons (carried out by means of the

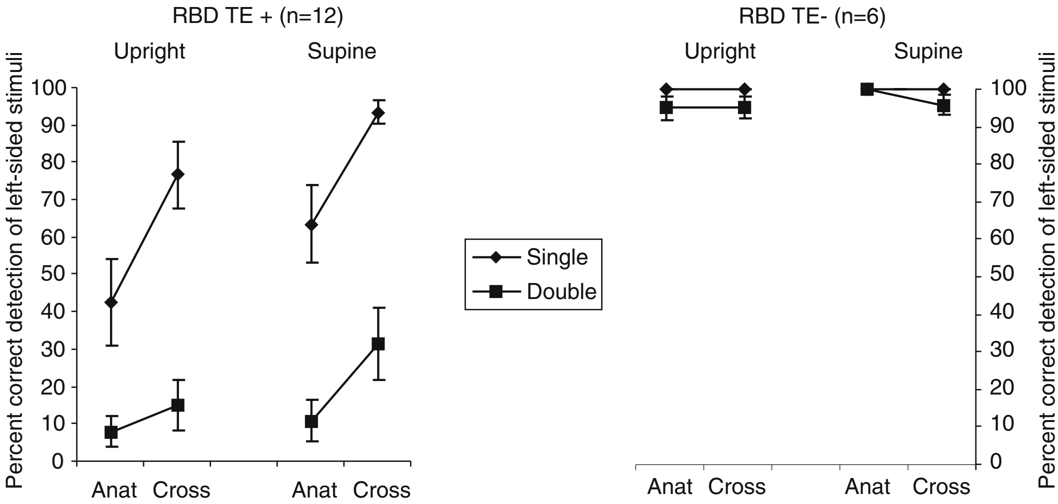

Fig. 2 Accuracy in detecting left-sided stimuli for the two RBD patients groups under different testing conditions. Error bars represent s.e.m

Newman–Keuls test). Indeed, difference in accuracy for single and double stimuli conditions was 3.5% in TE- ($p=0.12$) and 52.7% in TE+ ($p=0001$) patients, respectively. The factor Posture of the Body resulted significant [$F(1,16)=11.14$, $p=0.004$] insofar as accuracy in detecting left-sided stimuli was higher when patients were in supine (74.3%) than upright (66.5%) position. Since both TE+ and TE- patients detected left-sided stimuli much more accurately in supine than upright position the interaction Group x Posture of the Body was only marginally significant [$F(1,16)$ = 3.45, $p=0.081$]. It is worth noting, however, that the Supine minus Upright difference was significant in TE+ (14.2%; $p=0.0021$) but not in TE- patients (1.5%; $p=0.31$).

The factor Position of the Hands in space was also significant [$F(1,16)=4.77$, $p=0.044$] because accuracy in detecting stimuli delivered to the left hand was higher when it was in crossed (75.9%) than anatomical position (64.9%). Finally, the significance of the interaction Group x Position of the Hands [$F(1,16)=8.58$, $p=0.010$] reflects the fact that a better performance in crossed rather than anatomical position was typical of the TE+ group. Indeed the difference of correct detections in crossed minus anatomical conditions was significant in TE+ (+22.9%, $p=0.0024$) but not in the TE- group (−1.04%, $p=0.6$). No other interaction reached significance. In particular, the insignificance of the interaction Posture of the Body by Position of the Hands [$F(1,11)=0.38$, $p=.848$] suggests that the difference between anatomical and crossed position of the hands was comparable in the two different gravitational conditions; in other words, the crossing effect did not change across different body positions.

In the clinical test for assessing tactile extinction, TE+ patients omitted stimuli delivered to their left contralesional hand also under single stimulation (see Table 1). The presence of a primary somatic deficit in this group can in principle mask possible modulations of left-sided detection contingent upon spatial and postural changes. It is worth noting, however, that even the TE+ patients with the most severe impairment in detection of single left-sided stimuli showed an increase in accuracy in detecting stimuli in crossed positions (see Table 2).

Detection of right-sided stimuli in RBD patients

In single stimuli conditions, both TE- and TE+ patients detected perfectly right-sided stimuli in all the experimental blocks. In contrast, in double stimuli conditions there were omissions of right-sided stimuli in both groups of patients. Therefore, arcsin transform of the correct detections of right-sided stimuli in double stimulation conditions were entered in a mixed-model ANOVA with Group as a between-subjects factor, and Posture of the Body (upright vs. supine), and Position of the Hands (anatomical vs. crossed) as within-subjects factors. The factor Position of the Hands was significant [$F(1,16)=6.68$, $p=0.020$] because the overall accuracy in detecting right-sided touches in double stimuli conditions was higher when the right hand was in anatomical (99.4%) than crossed position (95.9%). No other effects or interactions reached significance.

Accuracy in healthy controls

Healthy controls performed errorless in all single stimulus conditions, and made only very few errors in the more demanding double simultaneous stimulation conditions (28 out of 1,920, corresponding to 1.5% of trials). Although such a number of errors was too small to be entered into any quantitative analysis, it can be noted that accuracy seems to be higher in an anatomical than a crossed position (100 vs. 97% of the hits), and in the supine than the upright position (99 vs. 98% of the hits).

Table 2 TE+ patients' individual performances in the experimental test (percent correct detections)

No.	Single Stimulus				Double Stimuli			
	Upright anatomical	Upright crossed	Supine anatomical	Supine crossed	Upright anatomical	Upright crossed	Supine anatomical	Supine crossed
7	80	100	90	100	35	15	45	35
8	60	100	80	100	0	5	0	50
9	100	80	100	80	5	80	10	90
10	100	90	100	90	35	40	50	50
11	80	100	80	100	0	0	0	10
12	40	70	50	70	0	5	0	0
13	20	60	70	100	20	25	25	55
14	20	80	100	100	0	0	0	0
15	10	40	50	100	0	0	0	0
16	0	100	40	100	0	5	0	80
17	0	100	0	100	0	5	0	5
18	0	0	0	80	0	0	0	0

Discussion

The present study investigated whether the reduction of gravitational inputs, obtained by placing subjects in a supine posture, can modulate the performance of RBD patients in detecting tactile stimuli delivered to their hands. Moreover, the study explored whether modulation of performance contingent upon postural changes of the entire body (upright or supine posture) interacts with the possible modulation of performance contingent upon positional change of hands in space (anatomical or crossed). RBD patients with or without tactile extinction and healthy controls were required to detect single and double simultaneous tactile stimuli delivered to the dorsum of their hands. This very simple bed-side test was able to dissociate somatotopic and spatial components underlying the somatosensory deficits observed in brain-damaged patients (Smania and Aglioti 1995; Aglioti et al. 1999). The test was delivered in experimental blocks where full body posture and hands position were orthogonally varied.

Results show that variations of both body posture and position of hands may influence the performance of RBD patients with tactile extinction. In particular, our study shows, for the first time in the tactile domain, that the postural manipulation of the entire body also influences the degree of tactile detection. Indeed, TE+ patients' accuracy in detecting left-sided stimuli was significantly higher in supine than upright posture (average supine minus upright difference = 14.2%). This beneficial effect on performance can be mainly ascribed to "extinguent" patients insofar as TE-patients performed with comparable accuracy in supine and upright posture. Our clinical study does not allow us to draw any definite conclusion about the mechanisms underlying the amelioration of tactile detection observed in supine position. In keeping with studies showing that increasing arousal may ameliorate spatial neglect (Robertson et al. 1998), one may observe that the better performance in supine posture is a simple arousal effect. Although it is entirely possible that different degrees of arousal are linked to different postures, non specific arousal effects are unlikely to explain the finding that the advantage of lying supine is much higher in TE+ than TE- patients. In keeping with studies in the visual domain (Pizzamiglio et al. 1997), our results suggest that changes in the quality and intensity of gravitational information from the otolith system in supine position allows to compensate for the post-lesional bias towards the right ipsilesional personal space. Finally, another plausible, although somewhat speculative explanation, can be offered. The upright posture, that is the typical alert position, may induce an attentional bias towards the extrapersonal space, thus making the individual prone to act in space, in response to visual and auditory stimuli. By contrast, the supine posture which is the typical resting position, may induce an attentional bias towards the personal space, thus improving tactile awareness. The finding that the detection of left-sided single stimulus was more accurate in supine than upright posture, independently from the position of the hands, supports this interpretation.

As shown in Table 1, a primary somatic deficit may be present in TE+ patients. Such a deficit would in principle prevent modulation of left-stimuli detection under single stimulation conditions. These patients, however, were much more accurate in detecting stimuli delivered to their left hand when it was in a crossed rather than in an anatomical position (crossed minus anatomical difference =22.9%). This effect was absent in the TE- group. The fact that all the TE+ patients, including those who have omitted 100% of the left single stimuli in the preliminary test, improved their accuracy in detecting stimuli under crossed conditions, clearly demonstrates that these patients suffered from an attentional/representational deficit besides a sensory impairment and can thus be correctly labelled as TE+.

This amelioration was found in both single (52.9% of the hits in anatomical vs. 85% of the hits in crossed position) and double simultaneous stimulation condition (9.4% of the hits in anatomical vs. 23.2% of the hits in crossed position). The significance of the main effects (posture of the body and position of the hands) and the insignificance of their interaction clearly indicate that the difference between the anatomical and the crossed position of the hands was comparable in the two different gravitational conditions, i.e., the effects of crossing of hands did not change in the different full body postures. In other words, the beneficial effect of crossing the hands did not depend on the body posture, as well as the beneficial effect of lying supine was independent of the spatial position of the hands. Thus, the improvement of performance dependent upon the full body posture and that dependent upon hands crossing should rely upon separate mechanisms.

All in all, our results are in keeping with studies indicating that the capability of RBD extinguent patients to report simple somatic stimuli is not only linked to somatotopic coordinates, but also related to several, distinct spatial frames of reference (Smania and Aglioti 1995; Vallar 1997; Aglioti et al. 1999; Tinazzi et al. 2000; Moro et al. 2004). However, our findings extend current knowledge by showing that gravity has important implications for somatic processing. Given the fact that the groups selection was based on the presence of tactile extinction, it comes as no surprise that the overall performance of the TE- group was much better than that of the TE+ group (overall accuracy 98.2 vs. 42.6%). It is worth noting that the improvement in detection of left-sided stimuli dependent upon changes of both full body posture and hands position, occurred not only in the demanding double simultaneous stimulation condition but also in single stimulation conditions. Thus, the presence of tactile extinction and/or neglect results in severe deleterious consequences on the somatosensory abilities of RBD patients. This is in keeping with studies demonstrating that the somatosensory deficits shown by RBD extinguent patients are not only linked to somatotopic coordinates, but also modulated by higher order related variables (Vallar 1997).

Detection of right-sided stimuli in single stimulation conditions was perfect in both groups of RBD patients. However, right-hand accuracy in double simultaneous stimulation condition was not errorless. Indeed, both TE+ and TE- patients were significantly more accurate in detecting double stimuli delivered to the right hand when it was in an anatomical (99.4%) rather than crossed position (95.9%). This effect was comparable in supine and upright body position. More importantly, such a performance did not discriminate between TE- and TE+ patients, suggesting that crossing the hands leads to a significant impairment of the capability of RBD patients to detect somatic stimuli delivered to their ipsilesional, unaffected hand. This deleterious effect of crossing the hands on the accuracy in detecting right-sided accuracy is in keeping with previous research (Aglioti et al. 1999; Bartolomeo et al. 2004). That the impairment of right hand accuracy reported here does not seem to depend on the presence and/or severity of tactile extinction and neglect is somewhat counterintuitive and deserves further research.

Healthy controls, although perfect in single stimulation conditions, failed to detect some stimuli in the most attention demanding, double simultaneous stimulation condition. Although controls seem to show a higher accuracy in anatomical vs. crossed position and in supine vs. upright posture, the consistency of these effects should be tested by more sensitive tests.

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