PAPER

The influence of limb crossing on left tactile extinction

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Background: Previous research on patients with left tactile extinction has shown that crossing of hands, so that each hand is on the opposite side of the body midline relative to the other, improves detection of stimuli given to the left hand.

Objectives: To study the influence of the spatial position of limbs on left tactile extinction, and its relations with left visual neglect.

Methods: Normal participants and patients with right cerebral hemisphere damage and left tactile extinction were asked to detect single or double light touch stimuli applied to their cheeks, hands, or knees with their arm and legs either in anatomical or in crossed position, increasing the attentional load of the task.

Results: In patients with left extinction, limb crossing caused a deterioration in performance for stimuli applied to right body parts, with only a tendency to an improvement in detection for left body parts (only two of 24 patients showed substantial (>20%) improvement in left extinction after limb crossing). After crossing, left limb detections of double stimuli decreased with increasing degrees of visual neglect.

Conclusions: In conditions of high attentional load, limb crossing may impair tactile detection in most patients with left extinction, and particularly in those showing signs of left visual neglect. These results underline the importance of general attentional capacity in determining tactile extinction. Attentional and somatotopic mechanisms of extinction may assume different weights in different patients.

Brain damaged patients may report only the stimulus ipsilateral to their lesion when stimulated on both sides, despite being able to report a single stimulus wherever applied. This disorder, called extinction[1] or sensory inattention,[2] is clinically defined as the "recognition only on the intact side of bilaterally and simultaneously presented stimuli,"[3] and can occur in different sensory modes: visual,[4 5] somatosensory,[2 6] acoustic,[7] olfactory,[8] and even cross modally.[9–11] Accounts of extinction typically emphasise either a sensory problem not severe enough to impair perception of single stimuli,[1 7] or an attentional disorder favouring ipsilateral over contralateral stimuli,[2] or both. The sensory and attentional mechanisms may reflect damage to different neural structures: the ascending pathways in the subcortical white matter for the sensory mechanism, and frontal or parietal cortical regions for the attentional mechanism.[4]

Concerning extinction in the somatosensory mode, or tactile extinction, several findings suggest that it is not exclusively determined by sensory mechanisms. First, left extinction may appear or be enhanced when patients look towards the right side.[12] On the other hand, contralesional awareness may be improved by looking at or intentionally moving to tactile stimuli rather than receiving them passively.[10 13–15] Second, there is the possibility of observing cross modal, visual-tactile extinction,[9 10] in which a visual stimulus can extinguish a tactile one. Third, there is the fact that tactile extinction seems to be more frequent after right than after left brain damage,[4 6 16] thus paralleling the pattern of occurrence of unilateral neglect. Finally, Moscovitch and Behrmann[17] showed that extinction in patients with unilateral neglect may have a directional component. When the wrist of one hand was touched simultaneously on its left and right side, patients extinguished the stimulus contralateral to the brain lesion, independent of the hand that was stimulated (left or right), and of its position (palm up or palm down).

Aglioti and coworkers recently confirmed that tactile extinction does not depend solely on sensory factors. Smania and Aglioti[18] examined the detection of light tactile stimuli applied on one or both hands of normal individuals and 16 right brain damaged patients. Participants were tested with their hands either in anatomical position, or crossed so that the left hand was placed to the right of patient's midline and vice versa. They found that crossing the hands improved the patients' performance by 32.5% for the left hand and left detections for the right hand substantially unchanged. In contrast, crossing impaired the controls' performance by around 5% for either hand.

The investigators proposed that the subjects' performance relied upon two different representations: a somatotopic representation and an extrapersonal spatial representation. Right brain damage would impair the left part of both representations, and cause the right part of the hemispace to be overrepresented. Accuracy of detection for the left hand would thereby improve when the left hand is placed in the right hemispace. However, this account would have predicted an impairment of right hand detection in the crossed condition, that is, when the right hand is situated on the left, impaired side, but Smania and Aglioti found no substantial change in that condition.[18]

In a second study, Aglioti *et al* employed a similar experimental paradigm in a larger patient sample (36 right brain damaged patients), but this time the hands (in a crossed or uncrossed position) were either across the body midline or both in the right or in the left hemispace.[19] Results showed an improvement in left hand detection by 30% in the crossed position, which occurred independently of the location of the hands (central or lateral); thus the source of the effect seemed to be the position of the hands with respect to each other, without reference to the body midline. On the other hand, crossing impaired performance for the right hand by 3%, but only in the most severely impaired patients—that is, those omitting at least 70% of left sided stimuli under double stimulation and at least 50% of single left sided stimuli.

However, Vaishnavi *et al* also explored the effect of limb crossing on extinction and found that crossing induced an average 5% deterioration in performance for left hand detections in a group of 10 right brain damaged patients.[15] Only two patients showed some improvement (8%) after crossing (see their table 3, patients LAB and GS). Performance for the right hand remained at ceiling both in anatomical and crossed positions.

Perhaps these discrepancies resulted from different impairments being at work in different patients. For example, in Aglioti's 1999 study,[19] crossing may have impaired stimulus detection on the right hand only for patients with a severe asymmetry in attentional orienting, as suggested by their tendency to omit even single left sided stimuli. If so, then increasing the possible loci of simulation in a tactile extinction paradigm, and thereby taxing the already biased processing capacities of right brain damaged patients, should allow one to observe a more systematic detrimental effect of limb crossing for detections on the right body parts. If, on the other hand, extinction depends on a representational impairment,[18] then increasing the possible stimulus sites should not change the pattern of results observed by Aglioti and coworkers.[18 19] That is, crossing should improve detection for left body parts and leave performance for right body parts substantially unchanged, at least for patients with milder forms of extinction.

A further question of interest concerns the relations between tactile extinction and signs of visual neglect in the extrapersonal space. There is functional and anatomical segregation of the brain mechanisms which process personal and extrapersonal space, as shown by neurophysiological studies in the monkey[20] and by human lesion studies.[21] In support of this distinction, tactile extinction has been found to correlate poorly with tests of extrapersonal visual neglect.[22] If, however, the effect of limb crossing involves a recoding of personal space into extrapersonal coordinates,[18] then this effect might be found to correlate with neglect signs on paper and pencil tests.

To explore these issues, we examined right brain damaged patients with left tactile extinction and normal individuals, using a task involving the presentation of tactile stimuli on their cheeks, hands, and knees, both in anatomical position and after crossing of arms and legs. Double stimuli were given either to homologous or to non-homologous body parts (for example, left hand and right knee). Thus patients had to monitor six possible loci of stimulation at any given time. The number of patients studied ($n = 24$) was relatively larger than in most previous studies involving limb crossing, to increase the possibility of observing individual differences in performance. The relation of crossing induced changes with the presence and degree of visual neglect was explored by correlating these changes with patients' performance on a neglect battery, including tests of target cancellation, line bisection, drawing copy, and identification of overlapping figures.

METHODS

Participants

Twenty four patients with unilateral lesions in the right hemisphere and left tactile extinction and 10 subjects without neurological impairment participated in the study after giving their informed consent. The study was carried out in accordance with the guidelines of the Declaration of Helsinki. Patients and controls did not differ in age or educational level (both t values <1). All patients underwent a preliminary examination of tactile extinction following a standard clinical procedure[22] consisting of six single unilateral stimuli (left or right hand, left or right knee, left or right cheek) and six double simultaneous stimuli (both hands, both knees, or both cheeks, each repeated twice), delivered to the blindfolded patient according to a previously randomised sequence. Patients were included in the study if they detected at least one single left stimulus per body part and extinguished at least one left stimulus under double stimulation. Table 1 shows the participants' demographic and clinical characteristics.

Procedure

Tactile detection task

Participants were seated blindfolded in a comfortable chair. The examiner gave light touch stimuli with the index fingertips. In the "anatomical" condition participants seated with hands on their lap. In the "crossed" condition, participants crossed their legs and arms, with the right limbs positioned over their left homologues. Stimuli were given to participants' cheeks, hands (dorsum), and knees. For each condition (anatomical or crossed), there was a basic sequence of 12 single stimuli (two for each body part and side of space), 24 double stimuli on homologous sites (two for each cheek, five for each hand, and five for each knee), and 12 double stimuli on non-homologous sites (two for each body part and side of space). Double stimuli were always given to body parts on the opposite sides of the body. To avoid ambiguities in the interpretation of responses, participants were asked to respond both by verbally localising the stimulated body part and by moving or touching it. The basic sequence was repeated four times, following an ABBA design, with A = anatomical and B = crossed for half of the participants, and the reverse assignment for the other half. Results of the two repetitions of each condition (anatomical or crossed) were pooled together.

Neglect battery

In the cancellation tests, a horizontal A4 sheet was presented to the patient, who was asked to cancel targets of various kind that were scattered on it: lines[23] or "A"s among other letters.[24] In the overlapping figures task,[25] patients were requested to identify five patterns of overlapping linear drawings of common objects. Each pattern included a central object (for example, a basket) with a pair of objects depicted over each of its sides (such as a lamp and a watch on the left side, a pipe and a key on the right side). The line bisection test was originally described by D'Erme *et al*.[26] It consists of eight lines horizontally disposed in a vertical A4 sheet, in a fixed random order. There are 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, patients copied a linear drawing representing a landscape consisting of a house and four trees,[27] presented on a horizontal A4 sheet.

Data analysis

To obtain a quantitative measure of spatial bias in each component test of the visuospatial battery, laterality scores were computed for each of the neglect tests using the following procedure. For the line bisection test, the score was 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—that is, 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

Table 1 Demographical and clinical characteristics of right brain damaged patients (P01–24) and normal controls (C01–10)

Participant	Sex/age/years of schooling	Locus of lesion	Weeks since symptom onset
P01	M/67/5	Frontal, parietal	2
P02	M/46/13	Occipital, temporal	4
P03	F/50/5	Frontal	2
P04	M/68/8	Frontal, parietal	12
P05	M/71/14	Basal ganglia	1
P06	M/52/9	Internal capsule, thalamus	22
P07	M/62/5	Parietal, occipital	2
P08	F/72/6	Temporal, parietal	4
P09	M/50/17	Frontal, parietal, temporal	28
P10	F/80/12	Temporal, parietal	2
P11	M/81/5	Temporal, parietal	1
P12	M/74/15	Temporal, parietal	1
P13	M/67/13	Frontal, parietal, temporal	2
P14	F/66/8	Parietal	3
P15	M/71/5	Temporal	2
P16	M/69/13	Temporal, parietal, occipital	5
P17	F/75/13	Frontal, parietal, temporal	6
P18	M/60/8	Internal capsule, thalamus	5
P19	F/70/4	Temporal	2
P20	M/73/19	Thalamus	2
P21	M/76/5	Parietal	3
P22	M/60/8	Frontal, parietal	2
P23	F/73/5	Temporal, parietal	2
P24	M/74/5	Temporal, parietal	2
C01	F/70/12		
C02	M/61/8		
C03	M/76/13		
C04	M/67/8		
C05	F/60/13		
C06	F/65/6		
C07	M/64/13		
C08	F/61/12		
C09	F/69/8		
C10	M/71/8		

C, control; F, female; M, male; P, patient.

of spatial bias which is independent of the overall level of performance (for example, of the total number of cancelled targets). 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 undertaken 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 (maximum +1.97, corresponding to a single item cancelled on the right). The landscape copy was scored by subtracting from 6 one point for each tree completely copied and two points for the house. Scores could range from 0 (all the items completely copied) to 5.5 (only the right half of a single tree copied).

The proportions of correct detections in the tactile detection task for each participant and condition were arcsin transformed and entered into separate repeated measures analyses of variance (ANOVA) for normal participants and for right brain damaged patients. The stimulated body part (cheek*, hand, or knee), its anatomical side (left or right body parts), the type of stimulus (single, double on homologous body parts, or double on non-homologous body parts), and the limb position (anatomical or crossed) were entered as factors. Theoretically relevant results were followed up by Tukey HSD tests.

*Although there was no straightforward reason to expect that limb crossing had any effect on detection accuracy on the cheeks, it could have influenced performance in indirect ways (for example, through changes in general arousal due to proprioceptive stimulation).

RESULTS

Normal participants performed at or near ceiling in all conditions (fig 1A), but were more accurate in the anatomical position (99.7% accuracy) than in the crossed position (99.1%), $F(1,9) = 8.65$, $p<0.05$. This effect interacted with the type of stimulus, $F(2,18) = 5.28$, $p<0.05$, because crossing decreased performance for double homologous stimuli (Tukey test, $p<0.01$), but not for the other types of stimuli. No other effects or interactions reached significance.

Right brain damaged patients' performance (fig 1B) was affected by the stimulated body part, $F(2,46) = 65.86$, $p<0.0001$, because patients detected a touch on cheeks better (87.8%) than stimuli on hands (67.6%) or knees (68.9%) (Tukey test, all p values <0.0005). Patients detected more stimuli on the right side (93.7%) than on the left side (55.8%), $F(1,23) = 151.26$, $p<0.0001$. These effects interacted ($F(2,46) = 19.43$, $p<0.0001$) because performance was worse for the left hand (43.8%) and knee (46.9%) than for the left cheek (76.7%) (all p values <0.0005). Accuracy decreased from single stimulation (94.5%) to double homologous stimulation (69.0%) and to double non-homologous stimulation (60.6%), $F(2,46) = 139.63$, $p<0.0001$. As expected in patients with left extinction, these effects interacted ($F(2,46) = 37.75$, $p<0.0001$) because patients detected fewer stimuli on their left body parts with double stimulation than in the other conditions (all p values <0.0005). The body part interacted with the type of stimulus ($F(4,92) = 8.57$, $p<0.0001$) because the fall in accuracy from single to double stimuli was more substantial for limbs than for cheeks. The limb position (anatomical or crossed) had no effect on overall performance ($F(1,23) = 1.35$) but interacted with the side ($F(1,23) = 10.40$, $p<0.005$), because crossing non-significantly improved performance for left body parts by 2.6%

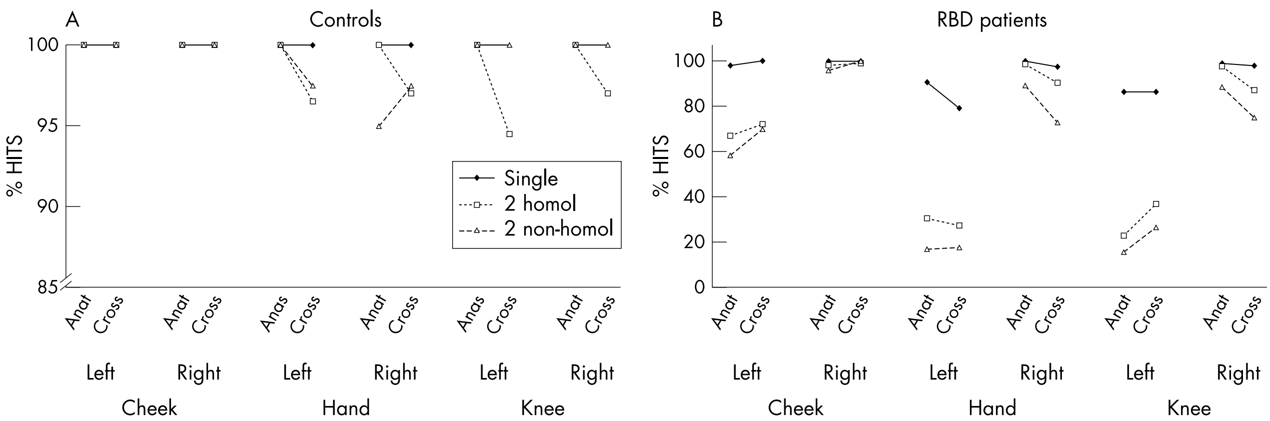

Figure 1 (A) Accuracy of detection (percentage of hits) with single stimulation and with double stimulation in normal controls on homologous (2 homol) or non-homologous (2 non-homol) body parts, with limbs either in anatomical or crossed position. (B) Accuracy of detection (percentage of hits) under single stimulation and under double stimulation in right brain damaged patients on homologous or non-homologous body parts, with limbs either in anatomical or crossed position.

($p = 0.51$) but decreased performance for right body parts by 5.4% ($p<0.05$). Limb position also interacted with side and stimulus type ($F(2,46) = 6.29$, $p<0.005$), because crossing resulted in deterioration of performance for right body parts, especially with double non-homologous stimulation (8.7% decrease, $p<0.05$). No other effect or interaction reached significance.

A potential concern in the interpretation of these results comes from the fact that crossing decreased normal participants' accuracy on double stimulus detection. Thus the crossing-induced deterioration we found for right limb stimulation in extinction patients might simply result from intrinsic differences between task conditions. To address this possibility, we conducted a mixed design ANOVA with participants (controls, patients) as between-subjects factor and the same within-subject factors as for the previous analyses. If crossing induced different rates of detection of double stimuli in patients and in controls, then an interaction should occur between participants, limb position, and side of stimulation. This was indeed the case ($F(1,32) = 4.70$, $p<0.05$). Planned comparisons showed that the crossing-induced deterioration of detection of double stimuli on the right limbs was much larger in patients (12%) than in controls (1.8%) ($F(1,32) = 5.77$, $p<0.05$).

To see whether crossing decreased right body part detections only in patients with the most severe impairment—as reported in a previous study[19]—we conducted a further ANOVA on data from only those patients ($n = 14$) who detected at least 75% of single stimuli and at least 25% of double stimuli in the anatomical position. The resulting pattern of effects and interactions was similar to that of the ANOVA done on the whole group of patients. In particular, the critical interaction between position and side of stimulus was still present ($F(1,13) = 10.03$, $p<0.01$), because crossing caused deterioration in right detections by 6% ($p<0.05$). Thus in our sample limb crossing impaired tactile detection on right body parts even in patients with milder somatosensory impairment.

Table 2 reports the participants' detection of double stimuli on limbs for the anatomical and crossed conditions, the size and direction of the modifications induced by crossing, and the patients' performance on paper and pencil neglect tests.

Inspection of table 2 suggests that there was no straightforward relation between crossing-induced modifications and the presence and amount of left visual neglect. Concerning, for example, the two patients who showed the larger improvement in left detections after crossing, patient 03 had no signs of visual neglect and patient 05 showed only a moderate rightward deviation on line bisection. The relation between crossing induced effects and visual neglect was explored more formally by calculating the correlation coefficients between the laterality scores obtained from paper and pencil tests and the effect of crossing on limb tactile extinction. If the effect of crossing involved a recoding of personal coordinates into extrapersonal coordinates,[18] then performance on paper and pencil neglect tests should positively correlate with crossing-induced modifications of tactile extinction. Contrary to this prediction, no significant positive correlation emerged between these measures (table 3). Unexpectedly, instead, *negative* correlations occurred between neglect tests and crossing induced changes of left limbs detection. This was because patients with severe degrees of left visual neglect were the least likely to improve when their left limbs were positioned on the right, non-neglected side (see, for example, patients 16 and 17 in table 2, who had severe left neglect and whose tactile detection for left limbs decreased by more than 20% after crossing).

DISCUSSION

We asked normal participants and right brain damaged patients with left tactile extinction to detect single or double light touch stimuli applied on their cheeks, hands, or knees before and after crossing of hands and legs, so that the left limbs were now on the opposite side relative to their right counterparts. Independently of crossing, patients showed better accuracy for stimuli delivered on their face than for stimuli applied on limbs, confirming previous evidence.[6] This result seems consistent with the view that the cortical sensory representation of the face is organised more bilaterally than that of the limbs, where it is strictly contralateral.[28 29] Sensation from the face would thus be more resistant to disruption resulting from unilateral brain damage.

Crossing the hands and knees induced changes in accuracy of detection of tactile stimuli. Normal participants showed a slight deterioration of performance in the crossed condition, especially for double simultaneous stimuli, suggesting that these situations are particularly demanding in terms of attention. For right brain damaged patients with tactile extinction, the deterioration of performance on limb crossing was substantial for the right limbs—six times larger than shown by controls. Aglioti *et al*,[19] using a task similar to ours but with stimuli given only to the hands, found an analogous

Table 2 Accuracy of detection (% of hits) for double stimuli given on limbs in the anatomical and crossed conditions, crossing induced changes (% hits anatomical− % hits crossed), and patients' performance on the neglect battery

Participant	Left anatomical	Left crossed	Left limbs change	Right anatomical	Right crossed	Right limbs change	Line bisection (% deviation)	Line cancellation (max 30/30)	Letter cancellation (max 30/30)	Overlapping figures (max 10/10)	Landscape drawing
P01	31	50	+19	94	75	−19	+11.64*	26/30†	21/26	9/8	0
P02	54	46	−7	100	100	0	+0.71	30/30	27/28	10/8	0
P03	4	46	+43	100	100	0	+0.48	30/30	30/30	10/10	0
P04	31	50	+19	94	75	−19	+0.24	25/30†	23/25	10/10	0
P05	0	36	+36	100	64	−36	+14.29*	30/30	28/29	10/8	0
P06	4	0	−4	100	89	−11	+7.38	30/29	29/25	10/10	0
P07	63	75	+13	100	88	−13	+16.67*	30/30	30/29	10/10	–
P08	29	29	0	89	71	−18	+0.71	28/29†	20/28	7/10	3
P09	32	39	+7	100	96	−4	+0.71	30/30	21/24	10/10	0
P10	4	0	−4	93	89	−4	+12.38*	30/30	26/23	5/7	1
P11	25	19	−6	88	88	0	+11.76*	–	9/16	10/9	1
P12	13	13	0	94	81	−13	+26.23*	0/4†	0/3	0/4	3
P13	25	0	−25	100	100	0	−9.73**	3/26†	0/3	4/10	1
P14	21	25	+4	79	54	−25	+20.48*	29/29	1/14	10/8	3
P15	50	69	+19	69	81	+13	−8.59**	30/30	23/27	10/10	1
P16	43	18	−25	100	89	−11	+60.00*	0/8†	–	0/8	3
P17	39	0	−39	100	100	0	+54.29*	0/9†	–	0/8	–
P18	25	32	+7	89	89	0	–	0/28†	0/4	–	–
P19	39	43	+4	96	61	−36	+23.57*	7/30†	19/27	9/10	1
P20	46	36	−11	100	68	−32	+2.27	29/30	0/9	2/9	3
P21	19	25	+6	100	63	−38	+14.70*	28/30†	6/27	7/9	1
P22	0	11	+11	100	86	−14	+37.62*	0/16†	30/24	3/8	3
P23	25	7	−18	100	93	−7	−32.19**	24/30†	5/25	3/10	3
P24	11	21	+11	96	93	−4	+65.24*	0/23†	0/1	7/10	3
C01	100	100	0	100	100	0					
C02	100	100	0	100	100	0					
C03	100	93	−7	100	93	−7					
C04	100	93	−7	100	96	−4					
C05	100	96	−4	100	96	−4					
C06	100	96	−4	100	100	0					
C07	100	100	0	93	93	0					
C08	100	100	0	100	100	0					
C09	100	100	0	100	96	−4					
C10	100	96	−4	100	100	0					

For line bisection, + indicates rightward deviation and − indicates leftward deviation. For cancellation tests, left/right correct responses are reported. Asterisks indicate pathological performance for standardised tests.
*Rightward or **leftward deviation greater than 2 SD from the mean performance of 30 normal age matched individuals.[39]
†The same group of normal individuals never omitted more than one item on this task.
C, control; P, patient; –, missing data.

Table 3 Correlation coefficients between the crossed-induced modifications of double detections on limbs and the laterality scores derived from the neglect tests

	Crossing: left	Crossing: right
Line cancellation	−0.32	0.09
Letter cancellation	−0.42	0.06
Line bisection	−0.16	−0.09
Landscape drawing	−0.44*	−0.11
Overlapping figures	−0.65*	−0.09

*z test, $p<0.05$

deterioration of performance only in extinction patients with severe impairment, who also omitted most single left stimuli. In the present study, by contrast, even patients who detected most left single stimuli showed this pattern of performance. This discrepancy may be explained if one considers that increasing the possible loci of stimulation also increases the attentional demands of the task, which thereby becomes more sensitive to disruption when the usual left–right position of the limbs is reversed.

Our results only partially confirmed the improvement of left body part detections after limb crossing shown in previous studies, in which the hands alone were stimulated.[18 19] We observed only a tendency in this sense for the left knee and cheek, but not for the left hand (see fig 1B). Inspection of individual performances (table 2) shows that about half the patients had some improvement of left limb extinction after crossing, but only for a third of patients was the improvement larger than 10%, and only for two patients was it larger than 20%. Also this discrepancy may underline the increased attentional load of our task as compared with the tasks employed by Aglioti and coworkers.

The possibility that the effect of limb crossing varies with the attentional load of the task (left body part improvement with low load, right body part deterioration with high load) supports the view that an attentional component participates in somatosensory extinction after right brain damage. Requested to monitor six possible anatomical loci for brief tactile stimuli, after crossing, patients made many more omissions when they had to orient their attention leftward to detect stimuli given to their right limbs. Although not statistically significant, the tendency for limb crossing to improve left detections on *cheeks* in right brain damaged patients (fig 1B) might also suggest that part of the influence of limb crossing observed in previous studies may simply be an arousal effect. Manoeuvres that increase arousal are known to ameliorate left visual neglect.[30]

As mentioned in the introduction, Vaishnavi *et al* found that limb crossing induced an average deterioration of performance for left hand detections.[15] They argued that extinction patients may suffer from an attentional bias in personal (somatotopic) space, rather than in extrapersonal space. They also proposed that tactile sensation might be biased towards personal rather than extrapersonal space. The alternate pattern could be true in individual cases. Heldmann *et al* found that repetitive peripheral magnetic stimulation of the left hand led to a significant reduction in left extinction, but had no effect on ipsilesional errors, whereas attentional cueing had no significant influence on left extinction, but increased right hand extinction errors.[31] Our results are not inconsistent with the proposal by Vaishavi[15] that tactile sensation might be biased towards personal rather than extrapersonal space, and are quite consistent with the proposal by Heldmann[31] that the high attentional demands of their tactile extinction task may account for the detrimental effect of contralesional cueing on ipsilesional performance.

Inspection of tables 2 and 3 and results of the correlational study suggest that there is no clear relation between the results of paper and pencil tests of neglect and the effects of limb crossing on tactile extinction. Contrary to the expectation that neglect patients might particularly benefit from limb crossing when detecting tactile stimuli on their left limbs (now placed on the right, ''intact'' side of space), the observed tendency was in the opposite sense. Patients with visual neglect tended to omit more left limb stimuli after crossing. If the crossed condition were particularly demanding in terms of attention, then neglect patients might have found this condition especially difficult, in keeping with evidence showing deficits of non-lateralised attentional capacities in these patients.[32–34] The present results seem also in line with other evidence showing poor correlations between tactile extinction and visuo-spatial tasks in right brain damaged patients,[22] and, more generally, between tasks performed under visual control and tasks carried out without visual control.[35–37] This evidence can be interpreted as suggesting that right visual objects exert a powerful ''magnetic attraction'' on patients' attention, thus enhancing left neglect, as compared with situations in which no visual stimuli are present.[25 38 39] Another possible interpretation of these discrepancies is that an attentional bias can manifest itself either in personal or in extrapersonal space, and that tactile sensation may be biased toward personal rather than extrapersonal space.[15] Some patients of the present series showed dissociations in performance between line bisection and target cancellation tasks, consistent with previously reported evidence.[40–43] The fact that patients with biased performance in either task are represented in the present sample suggests that our results generalise to both these patient populations.

Conclusions

Our results suggest that both somatotopic and attentional factors contribute to tactile extinction, perhaps with different weights in different patients. A rightward attentional bias for the personal space, with the possible addition of a more general, non-lateralised impairment of attentional capacity,[32 33] may affect right brain damaged patients' tactile detection by causing a dramatic deterioration in the performance of the right limbs when they are displaced leftward.

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