Binding Personal and Peripersonal Space: Evidence from Tactile Extinction

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Abstract

■ Behavioral and neurophysiological studies suggest that the brain constructs different representations of space. Among these representations are personal and peripersonal space. *Personal space* refers to the space occupied by our bodies. *Peripersonal space* refers to the space surrounding our bodies, which can be reached by our limbs. How these two representations are bound to give a unified sense of space in which humans act is not clear. We tested 10 patients with tactile extinction to investigate this issue. Tactile extinction is an attentional disorder in which patients are unaware of being touched on their contralesional limb if they are also touched simultaneously on their ipsilesional limb. We hypothesized that mechanisms that bind personal and peripersonal representations would improve these patients' awareness of being touched on their contralesional limbs. Visual–tactile integration and intentional movements were considered candidate mechanisms. Patients were more likely to be aware of contralesional touch when looking towards their contralesional limb than when looking towards their ipsilesional limb, and when actively moving on tactile probes than when receiving tactile stimuli passively. The improved awareness of being touched on the contralesional limb under these conditions suggests that cross-sensory and sensorimotor integration help bind personal and peripersonal space. ■

INTRODUCTION

The brain seems to construct multiple representations of space (Colby, 1998; Gross & Graziano, 1995). These representations include personal, peripersonal, and extrapersonal space. *Personal space* refers to the space occupied by the body (Vaishnavi, Calhoun, & Chatterjee, 1999; Coslett, 1998; Bisiach, Perani, Vallar, & Berti, 1986). *Peripersonal space* refers to space surrounding our body within the reach of our limbs (Ladavas, Di Pellegrino, Farne, & Zeloni, 1998; Brain, 1941). *Extrapersonal space* refers to space beyond the reach of our limbs (Previc, 1998; Brain, 1941). Human lesion studies and monkey neurophysiological studies provide evidence for this functional segregation of spatial representations.

Unilateral spatial neglect is a syndrome in which patients fail to report, respond, or orient to stimuli presented to the side opposite their brain lesion (Heilman, Watson, & Valenstein, 1993). This contralesional unawareness may occur in personal, peripersonal, or extrapersonal space. A dramatic dissociation of personal and peripersonal neglect occurs in patients that do not recognize their own contralesional limb. These patients recognize that they are looking at a hand and therefore are aware of the object in peripersonal space. Yet they do not recognize that the hand is their own, suggesting that they are unaware of this object as part of their personal space. Bisiach et al. (1986) investigated the relationship of personal and peripersonal/extrapersonal neglect formally in a large series of patients. Personal neglect was assessed by asking patients' to touch their contralesional limb with their unaffected hand. Peripersonal/extrapersonal neglect was assessed with a task in which patients cancel targets on an array placed before them. While many patients neglected both personal and peripersonal space, they found double dissociation of these deficits, suggesting that these representations are functionally segregated.

Since then, several groups have replicated the dissociation between personal and peripersonal neglect. To assess personal neglect, these groups have either used pointing tasks similar to the one used by Bisiach et al. (1986) or have observed the use of everyday objects such as combs and razors on contralesional parts of the body. To assess extrapersonal neglect, they have used drawing, cancellation, or line-bisection tasks (Cantagallo & Sala, 1998; Beschin & Robertson, 1997; Peru & Pinna, 1997; Guariglia & Antonucci, 1992).

Evidence for the segregation of peripersonal and extrapersonal space comes from reports of left neglect within one or the other of these sectors of space. Halligan and Marshall (1991) asked a patient to bisect lines of equal visual angles located either in peripersonal or in extrapersonal space. Their patient showed left neglect in peripersonal space but not in extrapersonal

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space. Cowey, Small, and Ellis (1994) reported patients with the opposite dissociation, finding more severe neglect in extrapersonal than in peripersonal space.

Neurophysiological studies in monkeys support the notion of neural circuits dedicated to coding peripersonal space. Neurons in area F4 in premotor area 6 and the putamen are most responsive to visual stimuli in peripersonal space (Graziano & Gross, 1993; Gentilucci et al., 1988). Similarly, neurons in the ventral intraparietal (VIP) area (Colby, Duhamel, & Goldberg, 1993), the medial intraparietal (MIP) area (Colby & Duhamel, 1996), and area 7b of the parietal lobe (Graziano & Gross, 1995) are most responsive to visual stimuli in peripersonal space. Graziano and Gross (1993) have argued that a neural circuit including at least premotor area 6, the putamen, and parts of parietal cortices is dedicated to coding peripersonal space. These regions are analogous to regions in the human brain, which when damaged produce deficits of spatial awareness.

The evidence from both human and monkey studies in support of the notion of distinct spatial representations raises the following questions. Why are humans not confused by these multiple spatial representations? How do humans perceive and act in space coherently? Why do we not experience space as a cubist environment, with multiple frames and representations competing for consciousness simultaneously? Such questions led Rizzolatti and colleagues to claim, "The fundamental problem now is to understand how these different space maps interact and give an introspectively unitary space percept" (Fogassi et al., 1996).

One approach to this problem of how different spatial representations might interact is to consider the integration of different sensory and motor systems. As an initial postulate, we suggest that specific sensory and motor systems are linked preferentially to distinct spatial representations. At the turn of the century, Herrick (1908) observed that smell is experienced as emanating from an object distant from the body, whereas taste is experienced as being produced by an object on the body (tongue). These different experiences of space occur despite the fact that both sensations are mediated chemically. Similarly, touch and vision may inherently mediate different relationships to space (Inhoff, Rafal, & Posner, 1992). Tactile objects are experienced as being on the body, whereas visual objects are experienced as being located at a distance. Consistent with this idea, Shelton, Bowers, and Heilman (1990) found that normal subjects orient attention away from the body during visual exploration and towards the body during tactile exploration. Therefore, touch may be linked more closely to personal space and vision may be linked more closely to peripersonal space. Integrating tactile and visual sensations may then help bind personal and peripersonal space.

The relationship of movement and perception is also of considerable interest. Theorists have suggested recently that much of perception serves to produce coherent actions (Colby, 1998; Goodale & Milner, 1992). Intentional movements mediate a complex interaction between personal and peripersonal space. In reaching to an object, an individual must coordinate the space occupied by their body and place it in register with locations perceived in peripersonal space. Therefore, linking movement and sensations may also serve to bind personal and peripersonal space.

To test the hypotheses that cross-modal and sensorimotor integration bind personal and peripersonal spatial representations, we investigated brain-damaged patients with tactile extinction. Patients with tactile extinction are unlikely to report tactile stimuli located in space contralateral to their damaged hemisphere when these stimuli are presented simultaneously with ipsilateral stimuli (Heilman et al., 1993). The syndrome cannot be explained by primary somatosensory loss since these patients are aware of touch on the contralesional side when there is no competing ipsilesional stimulation. Tactile extinction patients may have underlying deficit aligned to different reference frames (Behrmann & Moscovitch, 1994), such as in peripersonal space (Aglioti, Smania, & Peru, 1999) or in personal space (Vaishnavi et al., 1999). With extinction in peripersonal space, patients selectively extinguish touch to the left of their trunk even if their arms are crossed and their ipsilesional hand now falls in contralesional space. With extinction in personal space, patients selectively extinguish touch on their contralesional limb, regardless of where the limb is located in relation to the trunk of their body.

In this study, we used patients with tactile extinction in personal space. We tested the hypothesis that visual–tactile and tactile–motor integration would improve their contralesional awareness because these mechanisms bind personal and peripersonal representations.

RESULTS

Patient Description

We tested 10 right brain-damaged patients, 6 women and 4 men. The patients had an average age of 61.1 years and 11.1 years of schooling. Five of these patients had neglect based on the Behavioural Inattention Test (BIT, Wilson, Cockburn, & Halligan, 1987). Eight out of ten patients had damage to Brodmann's area (BA) 40 (supramarginal gyrus) while six had additional or separate damage to BA 22 (superior temporal gyrus). See Table 1 for details.

Experiment 1

The purpose of the first experiment was to assess these patients' abilities to detect unilateral tactile stimulation. We presented unilateral tactile stimulation on the left or

Table 1. Patient Characteristics

Patient	*Gender*	*Age*	*Years of Schooling*	*Months Postlesion*	*BIT Score*	*Lesion Site*[a]
EH	M	69	6	1	139	40,22
DC	F	67	10	36	140	40,22,39
JH	M	61	12	4	122[b]	40,22,6,44
CG	F	58	12	2	43[b]	40,22,21,4
CC	F	44	17	3	38[b]	40,39
LAB	M	61	13	15	27[b]	40,39,22,37,19,21,20,38,3,1,2,6,4,9,46,45,47,5,7
GS	F	40	12	1	138	40,2
HJ	M	60	11	20	135	17,18,19,36,28
BH	F	62	12	3	27[b]	22,21,38,4,6,44,9,32
LB	F	89	6	3	135	40

[a]Lesion sites refer to Brodmann's areas in the right hemisphere.

[b]Neglect is present.

right hand. They were not touched in some trials. In general, patients performed well, suggesting that they were able to detect contralesional stimuli. On average, they detected 89.8% of the times that they were touched on the left. All but one of the patients, GS, performed above 80% for the unilateral left trials. GS was correct for 71% of the unilateral left trials in Experiment 1. She was included in the study because she performed well in unilateral left stimulation in subsequent experiments and her contralesional awareness was modified by presentation of bilateral simultaneous stimuli. See Figure 1 for the group results. See Table 2 for details of patients' individual performances.

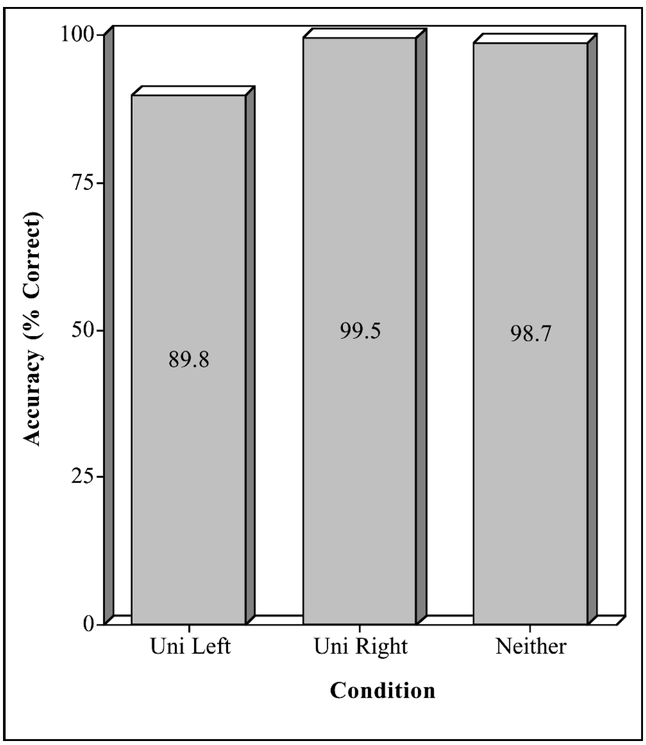

Figure 1. Mean percent accuracy for the entire group in Experiment 1. Uni Left refers to the condition in which patients were touched on the left hand. Uni Right refers to the condition in which patients were touched on the right hand. Neither refers to the condition in which patients were not touched at all.

Experiment 2

The purpose of this experiment was to find out if these patients with tactile extinction had deficits in personal

Table 2. Patient Performance in Experiment 1

Patient	*Neither*	*Unilateral Left*	*Unilateral Right*	*Overall Percent Correct*
EH	100	91	100	97
DC	100	100	100	100
JH	100	86	100	95.3
CG	100	85	100	95
CC	93	95	100	96
LAB	100	90	100	96.7
GS	100	71	96	89
HJ	94	82	99	91.7
BH	100	98	100	99.3
LB	100	100	100	100

The columns show the number of times out of 100 trials that patients reported stimulation accurately.

space or in peripersonal space. We contrasted their performance with their hands apart and their hands crossed. If their deficit was in personal space, then patients would continue to extinguish the left hand even when it was crossed and on the right side of their body. Hand position with respect to the trunk is irrelevant to a deficit in personal space. Alternatively, if the deficits were in peripersonal space, conceived of as a shell around the trunk (Previc, 1998), then they would extinguish the right hand when crossed and located in left peripersonal space.

Logistic regression analysis showed patients as a group were more aware of left-sided stimuli during bilateral presentation if their hands were uncrossed than when they were crossed: $G(10) = 176.7$, $p < .0001$. Analyzed individually, two patients, HJ and BH, were significantly more accurate ($p < .05$) with their hands apart than with the hands crossed. HJ, in particular, had a right occipital lesion, and did not have a lesion of the posterior inferior parietal lobe, which is more characteristic for patients with extinction. His accuracy with bilateral stimulation was high in this experiment, but his contralesional awareness was modified by presentation of bilateral simultaneous stimuli in subsequent experiments. Despite the variability in performance, all 10 patients continued to extinguish the left hand, regardless of position in space. All of the 10 patients thus exhibited primary deficits in personal space. See the group results in Figure 2. See the patients' individual data in Table 3.

Table 3. Patient Performance in Experiment 2 With Hands Apart or Crossed

	Neither		*Unilateral Left*		*Unilateral Right*		*Bilateral*	
Patient	*Ap*	*Cr*	*Ap*	*Cr*	*Ap*	*Cr*	*Ap*	*Cr*
EH	25	25	25	24	25	25	3	1
DC	25	25	25	25	25	25	1	1
JH	25	25	22	24	25	25	1	0
CG	25	25	18	18	25	25	0	0
CC	21	23	24	25	25	25	0	0
LAB	25	25	24	24	25	25	5	7
GS	25	25	25	23	25	25	1	3
HJ	25	25	24	21	22	25	24	16
BH	25	25	25	25	25	25	5	0
LB	25	25	25	25	25	25	1	0

The columns show the number of times patients reported stimulation accurately out of 25 trials. Ap refers to the hands apart condition and Cr refers to the hands crossed condition.

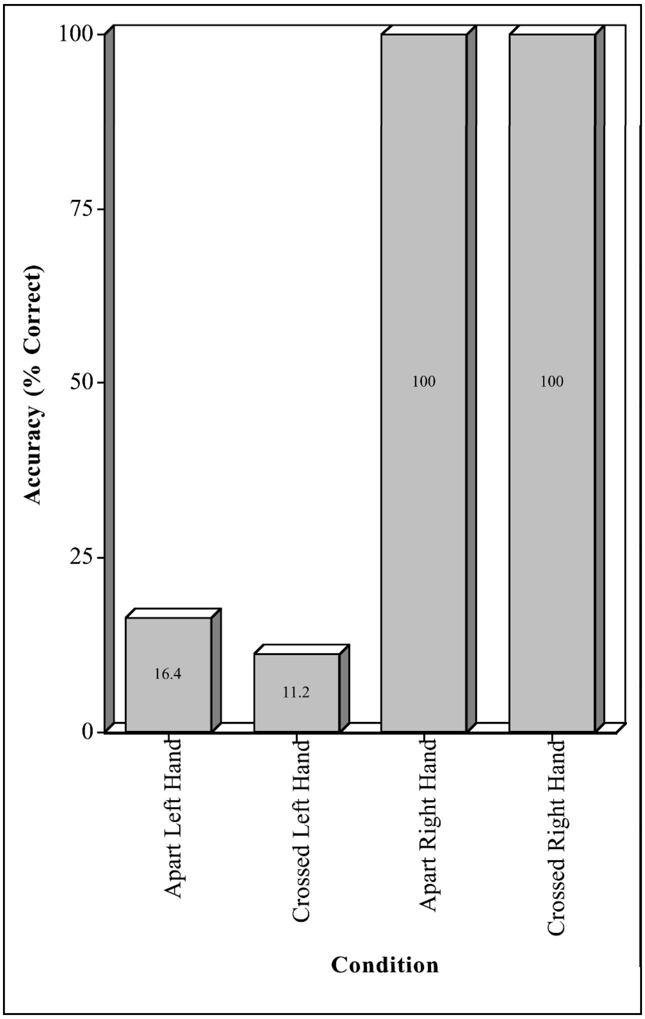

Figure 2. Mean percent accuracy for the entire group in Experiment 2 for the conditions in which patients were touched bilaterally. Apart Left Hand refers to the percent accuracy of reporting touch on the left hand with the hands apart. Crossed Left Hand refers to percent accuracy of reporting touch on the left hand with the arms crossed. Apart Right Hand refer to the percent accuracy of reporting touch on the right hand with the hands apart. Crossed Right Hand refers to percent accuracy of reporting touch on the right hand with the arms crossed.

Experiment 3

The purpose of this experiment was to test the hypothesis that visual input improves contralesional tactile awareness. As a group, the patients awareness of left-sided stimuli during bilateral presentation was modulated by the direction of their gaze: $G(10) = 402.9$, $p < .0001$. They were 5.7 times more likely to be aware of stimuli on the left when looking at the left than when looking at the right (95% confidence interval, 4.1 to 7.9). Analyzed individually, 6 of the 10 patients were more likely to report left-sided tactile stimulation when stimulated simultaneously when looking at the left hand than when looking at the

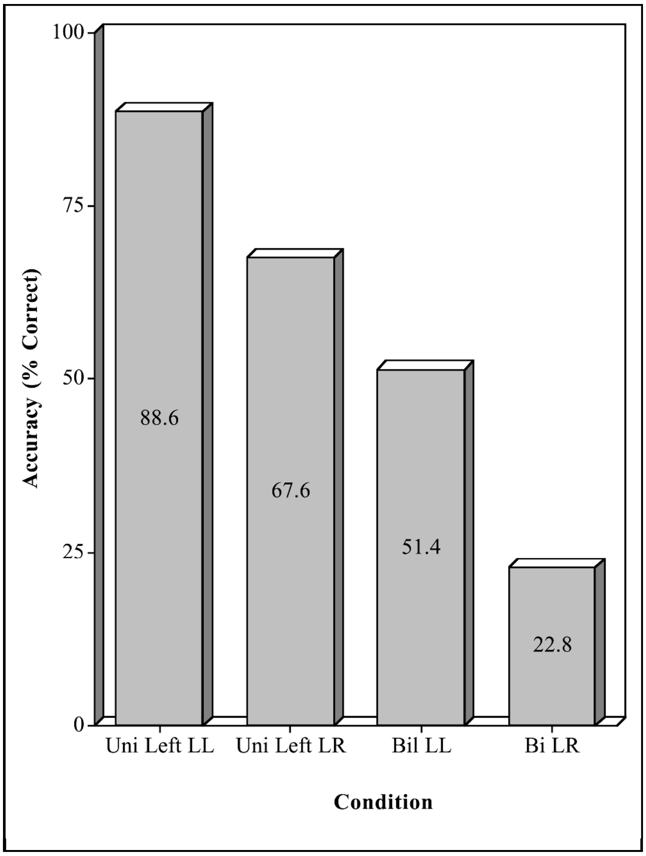

Figure 3. Mean percent accuracy for the entire group in Experiment 3 for the conditions in which patients were touched unilaterally. Uni Left LL refers to the condition in which patients were touched on the left and looked to the left. Uni Left LR refers to the condition in which patients were touched on the left and looked to the right. Bil LL refers to the condition in which patients were touched on both hands and looked to the left. Bil LR refers to the condition in which patients were touched on both hands and looked to the right.

right hand. Direction of gaze also affected awareness of unilateral left-sided stimulation. As a group, the patients were 9.2 times (95% confidence interval, 5.9 to 14.5) more likely to report left-sided unilateral tactile stimulation when looking at the left than when looking at the right: $G(10) = 529.1$, $p < .0001$. Analyzed individually, four of the patients were significantly less likely to report a left-sided unilateral tactile stimulus when looking right than when looking left. These data suggest that looking to the right inhibited tactile awareness of unilateral stimuli on the left. See Figure 3 for the group data. See Table 4a for the performance of all the patients in Experiment 3 and Table 4b and c for the individual statistical analyses.

Experiment 4

The purpose of this experiment was to test the hypothesis that intentional movements improve tactile awareness. To do so, we compared the results in passive (the subjects were touched by a probe) and

Table 4. Experiment 3 Results

(a) Patient Performance in Experiment 3

	Neither		*Unilateral Left*		*Unilateral Right*		*Bilateral*	
Patient	*Ll*	*Lr*	*Ll*	*Lr*	*Ll*	*Lr*	*Ll*	*Lr*
EH	50	49	***44***	***12***	47	48	***32***	***10***
DC	50	50	50	49	49	50	***27***	***3***
JH	49	50	***34***	***11***	49	50	0	0
CG	46	47	***36***	***1***	32	50	***35***	***0***
CC	32	46	***33***	***19***	50	49	***39***	***3***
LAB	50	49	48	48	49	49	16	23
GS	50	50	49	50	50	50	15	13
HJ	47	50	49	49	49	47	48	50
BH	50	50	50	50	50	49	***21***	***7***
LB	50	50	50	49	50	50	***24***	***5***

The columns show the number of times patients reported stimulation accurately out of 50 trials. Ll refers to the look left condition and Lr refers to the look right condition. Contrasting conditions that are significantly different ($p < .05$) are indicated in ***boldface***.

(b) Individual Analyses of Left-Sided Tactile Awareness With Bilateral Stimulation Modulated by Direction of Gaze, Experiment 3

Patient	*G(1)*	*p*	*OR*
EH	20.7	< .0001	7.1 (2.9, 17.5)
DC	30.5	< .0001	18.4 (5.0, 66.9)
CG	68.4	< .0001	171,134.0 (4.3×10^{-28}, 6.8×10^{37})
CC	60.7	< .0001	55.5 (14.5, 213.1)
BH	10.1	.0015	4.4 (1.7, 11,8)
LB	18.7	< .0001	8.3 (2.8, 24.4)

OR refers to odds ratios.

(c) Individual Analyses of Left-Sided Tactile Awareness With Unilateral Left Stimulation Modulated by Direction of Gaze, Experiment 3

Patient	*G(1)*	*p*	*OR*
EH	45.4	< .0001	23.2 (8.0, 67.8)
JH	22.3	< .0001	7.5 (3.1, 18.4)
CG	62.7	< .0001	125.8 (15.8, 999.9)
CC	8.0	.0048	3.2 (1.4, 7.2)

OR refers to odds ratios.

active conditions (the subjects intentionally moved their fingers on a probe). Five patients participated in this experiment. The other patients could not participate because of their contralesional paralyses. As a group, these patients were more aware of a stimulus on the left during bilateral presentation when they intentionally moved than when they received the stimulus passively: $G(5) = 92.6$, $p < .0001$. Patients were 7.2 times more likely to report stimuli on the left when actively moving on the stimuli than when passively receiving them (95% confidence interval, 3.6 to 14.3). Analyzed individually, four of the five patients were significantly more likely to report left-sided tactile stimulation with bilateral simultaneous tactile stimulation when moving their hands on the probe than when receiving the stimuli passively. See Figure 4 for the group data. See Table 5a for the patients' performance and Table 5b for individual statistical analyses.

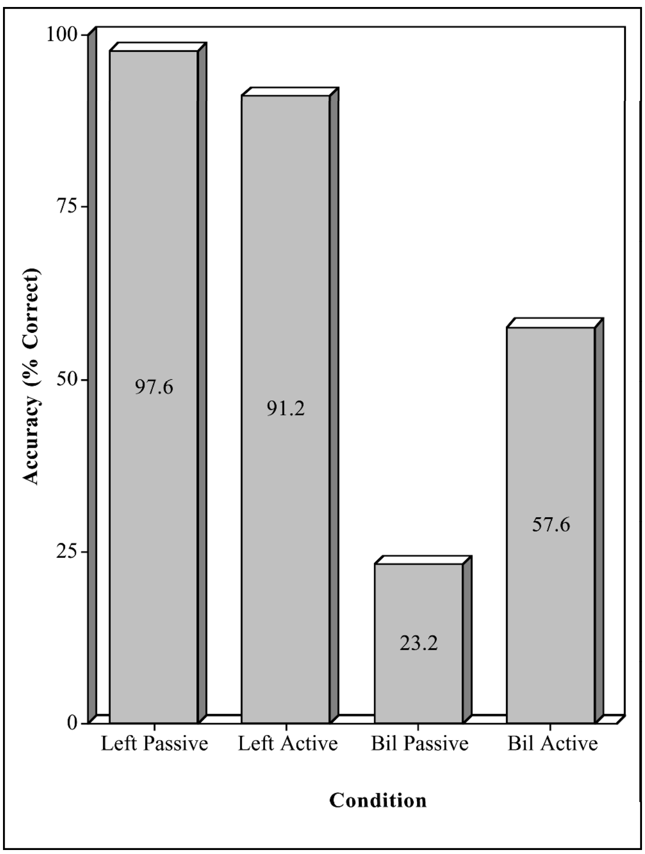

Figure 4. Mean percent accuracy for the entire group in Experiment 4. Left Passive refers to the condition with the patients passively receiving tactile stimuli on the left. Left Active refers to the condition with the patients actively engaging tactile stimuli on the left. Bil Passive refers to the condition with the patients passively receiving tactile stimuli on both hands. Bil Active refers to the condition with the patients actively moving both hands on the tactile stimuli.

Table 5. Experiment 4 Results

(a) Patient Performance on Experiment 4

	Neither		*Unilateral Left*		*Unilateral Right*		*Bilateral*	
Patient	*Pa*	*Ac*	*Pa*	*Ac*	*Pa*	*Ac*	*Pa*	*Ac*
EH	25	25	24	21	25	24	***4***	***15***
DC	25	25	25	25	25	25	***1***	***15***
GS	25	25	25	25	25	25	5	8
HJ	25	25	23	25	25	25	***18***	***24***
LB	25	25	25	18	25	25	***1***	***10***

The columns show the number of times patients reported stimulation accurately out of 25 trials. Pa refers to the passive condition and Ac refers to the active condition. Contrasting conditions that are significantly different ($p < .05$) are indicated in ***boldface***.

(b) Individual Analyses of Left-Sided Tactile Awareness With Bilateral Stimulation Modulated by Intentional Movements, Experiment 4

Patient	*G(1)*	*p*	*OR*
EH	10.8	.001	7.9 (2.1, 29.9)
DC	20.6	< .0001	36 (4.2, 310.4)
HJ	5.9	.015	9.3 (1.1, 82.8)
LB	10.6	.0011	16.0 (1.9, 138.0)

OR refers to odds ratios.

DISCUSSION

Cross-modal integration (between vision and touch) and sensorimotor integration (between touch and intentional movement) may help bind personal and peripersonal space, allowing humans to be aware of and act coherently on stimuli in their spatial environment. We investigated this idea using the clinical phenomenon of tactile extinction as a probe. We hypothesized that mechanisms that access peripersonal space would improve contralesional spatial awareness in these patients if they bind personal and peripersonal representations.

Tactile extinction patients may have a deficit in personal space (Vaishnavi et al., 1999) or in peripersonal space (Aglioti et al., 1999). Our patients predominantly had deficits in personal space since they continued to extinguish the left hand, regardless of its position in peripersonal space. The patients did show slightly less extinction with hands in their respective hemispaces than with their hands crossed. These data suggest deficits in personal and peripersonal space may interact in complex and subtle ways.

Our findings are consistent with reports by Di Pellegrino and Ladavas (1997) and Ladavas et al. (1998) that visual stimuli near the contralesional hand modulates tactile extinction. They report that when their patients fixated centrally, visual stimuli in the contralesional hemifield enhanced contralesional tactile awareness. We extend these findings by showing that patients' direction of gaze, rather than hemifield location of visual stimuli, can similarly improve contralesional tactile awareness. We are currently conducting experiments to investigate the relative contributions of vision and proprioception from different head positions on the modulation of tactile extinction. Our findings are also compatible with experiments in normal subjects showing that attention to stimuli in one sensory modality can enhance awareness of stimuli in a second modality (Driver & Spence, 1998; Spence & Driver, 1998).

The neurophysiological correlate of visual and tactile integration may be bimodal neurons found in the putamen, premotor area 6, and parietal areas 7b and intraparietal sulcus of the macaque (Iriki, Tanaka, & Iwamura, 1996; Graziano & Gross, 1995). These neurons are more responsive to visual stimuli located in peripersonal space close to their tactile receptive fields than if they are located further away in extrapersonal space (Gentilucci et al., 1988). This frontal–parietal–subcortical neural circuit may be important in constructing an integrated visuotactile representation (Ladavas et al., 1998) that binds personal and peripersonal spatial representations.

Our study also demonstrates that intentionally moving to tactile stimuli rather than receiving similar stimuli passively can improve tactile awareness. This finding is at odds with psychophysical data from normal subjects in which intentional movements raise tactile thresholds for awareness (Chapman, Bushnell, Miron, Duncan, & Lund, 1987). These data are also not explained easily by effects of cueing attention to one or the other side, since the patients moved their index fingers on both sides simultaneously. The notion that movements and sensations are linked in representing space also has a neurophysiological correlate. Neurons in the macaque putamen respond during both tactile stimulation and active movements of the monkey's arm to a target (Merchant, Zainos, Hernandez, Salinas, & Romo, 1997). Area 6 in the macaque has bimodal (visual–tactile) neurons that are active when the monkey reaches toward a target (Gentilucci et al., 1988). Our data suggest that the functional significance of such neuronal activity may be the phenomenological awareness of locations bound to personal and peripersonal space mediated by movement.

Although our patients as a group showed that vision and movement enhanced tactile awareness, there were individual exceptions. The reasons for these exceptions are not clear from the anatomy of their lesions. Most of our patients had lesions in the supramarginal (BA 40) and superior temporal gyrus (BA 22), which fits the classic idea that the posterior temporoparietal junction is critical in representing space. The modulation of their awareness by vision and movement may have been mediated by prefrontal and basal ganglia neurons dedicated to cross-modal and sensorimotor integration. However, the locations of their lesions did not distinguish the patients whose tactile awareness was modulated by our experimental conditions from those whose awareness was not. Further prospective studies may be needed to clarify the anatomic bases for these functional distinctions. It is possible that functional dissociations of the kind that we are observing do not map directly on to distinct anatomic regions (Chatterjee, 1998).

In summary, evidence from brain-damaged patients and monkey neurophysiology suggests that the brain constructs multiple representations of space. Given that the brain represents personal and peripersonal space distinctly, how are these representations bound together to give a coherent phenomenological awareness of space? We suggest that cross-modal and sensorimotor integration are two mechanisms that bind personal and peripersonal space.

METHODS

Subjects

Ten patients with contralesional tactile extinction following right hemispheric strokes, as determined by magnetic resonance imaging (MRI) or computerized tomography (CT), were enrolled in the study. All patients gave informed consent for the study, which was approved by the Institutional Review Board. Three of these patients were reported elsewhere (Vaishnavi et al., 1999). Patients were given the BIT (Wilson et al., 1987). The BIT is a general screening test for the presence of neglect. A score below 135 is considered abnormal. Patients were assessed initially for both tactile and visual extinction using conventional clinical bedside methods. Tactile extinction was assessed by applying light touch on the left hand, right hand, both hands, or neither hand while blindfolded. Visual extinction was assessed by a single brief flexion of the examiner's index finger in the left visual hemifield, right hemifield, both hemifields simultaneously, or in neither hemifield. The patients had to state where, if anywhere, they saw the flexion of the finger. None of the patients extinguished visual stimuli reliably. Two patients, GS and HJ, performed differently from the others but were included in the study because they showed contralesional tactile processing deficits. See Table 1 for patient characteristics.

Materials and Procedure

The patients sat at a table with their palms facing upward. The tactile stimuli consisted of coarse sandpaper (50 grit D weight) affixed to 15 × 3 cm flat sticks. Two centimeters of the sandpaper were moved on the palmar surface of the tip of the index finger to provide tactile stimulation. In the first experiment, patients reported verbally if they felt the stimulus on the right, left, or on neither hand. In all other experiments, they reported if they felt stimulation on the right, left, neither, or on both hands. Contrasting conditions in Experiments 2 (hands apart vs. crossed), 3 (look left vs. look right), and 4 (active vs. passive) were presented in an ABBA order. Trials within each condition were presented randomly. Responses were scored by two independent observers and videotaped for subsequent checks for accuracy.

Statistical Analyses

The data were analyzed as a group and as a series of single cases. Logistic regression analyses were used because the dependent variable was dichotomous, correct, or incorrect for each trial. The G statistic was computed to determine level of significance. Logistic regression also established odds ratios. Dummy variables were used to code each individual in the group analyses to minimize effects due to outliers.

Experiment 1

Each patient was blindfolded and touched with the tactile probe on the left, right, or neither hand for 300 trials, 100 in each condition. Trials were presented randomly.

Experiment 2

Each patient was blindfolded and assessed in two contrasting conditions. In the first condition, the patients had their hands separated by a comfortable distance (54 cm). In the second condition, they had their hands crossed so that the right hand was in the left side of space (with respect to the trunk) and the left hand was in the right side of space. There were 200 trials for each patient, 100 with the hands apart and 100 with the hands crossed.

Experiment 3

The patients were assessed in two contrasting conditions with their hands in their respective hemispaces (the canonical position). In one condition, the patients looked at their left hand while a shield visually obscured their right hand. In the other condition, the patients looked at their right hand while a shield obscured their left hand from view. Their trunk remained stationary while they directed their head and eyes to either direction. The stimulus probe was moved in all trials, but one centimeter above the patients' fingers on trials in which they were not touched. This movement of the probe ensured that they did not respond solely to seeing a moving probe even when the patients were not touched. There were 400 trials per patient, 200 with their gaze directed at their left hand and 200 with their gaze directed at their right hand.

Experiment 4

Each patient was assessed in two contrasting conditions while blindfolded, with their hands in their respective hemispaces. In the passive condition, the probe was moved on the patients' index fingers and in the active condition, the patients moved their index fingers on the probe. Five patients could not participate in this experiment because their left arms were paralyzed. There were 200 trials, 100 in the passive and 100 in the active condition.

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