Neuropsychological Evidence of an Integrated Visuotactile Representation of Peripersonal Space in Humans

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Abstract

■ Current interpretations of extinction suggest that the disorder is due to an unbalanced competition between ipsilesional and contralesional representations of space.

The question addressed in this study is whether the competition between left and right representations of space in one sensory modality (i.e., touch) can be reduced or exacerbated by the activation of an intact spatial representation in a different modality that is functionally linked to the damaged representation (i.e., vision). This hypothesis was tested in 10 right-hemisphere lesioned patients who suffered from reliable tactile extinction. We found that a visual stimulus presented near the patient's *ipsilesional hand* (i.e., visual peripersonal space) inhibited the processing of a tactile stimulus delivered on the contralesional hand (cross-modal visuotactile extinction) to the same extent as did an ipsilesional tactile stimulation (unimodal tactile extinction). It was also found that a visual stimulus presented near the *contralesional hand* improved the detection of a tactile stimulus applied to the same hand. In striking contrast, less modulatory effects of vision on touch perception were observed when a visual stimulus was presented far from the space immediately around the patient's hand (i.e., extrapersonal space).

This study clearly demonstrates the existence of a visual peripersonal space centered on the hand in humans and its modulatory effects on tactile perception. These findings are explained by referring to the activity of bimodal neurons in premotor and parietal cortex of macaque, which have tactile receptive fields on the hand and corresponding visual receptive fields in the space immediately adjacent to the tactile fields. ■

INTRODUCTION

Patients with unilateral brain lesion may fail to report a single stimulus presented on the contralesional side when a competing stimulus is shown simultaneously on the ispilesional side, even though they can report either stimulus when it is presented alone (Critchley, 1949; De Renzi, 1982). This phenomenon has been called extinction (Bender, 1952). The fact that extinction patients are able to report a single stimulus on the contralesional side shows that the deficit is not a mere reflection of a relatively low-level disorder of sensory processing, although a subtle sensory impairment could still be involved (see Làdavas, 1990).

Extinction phenomenon have been attributed to an unbalanced competition between concurrent targets for access to limited attentional resources (di Pellegrino, Basso, & Frassinetti, 1997; Ward, Goodrich, & Driver, 1994). The unilateral damage to a brain area with a contralateral field representation results in a reduction of competitive weights in the affected field. As a consequence, stimuli presented in the contralesional space evoke a weak activation of that portion of space, and therefore, they are extinguished due to the competition with stimuli presented in the intact ipsilesional space.[1]

Extinction may occur within different sensory modalities (unimodal extinction): visual (Làdavas, 1990; Ward et al., 1994; di Pellegrino & De Renzi, 1995), auditory (De Renzi, Gentilini, & Pattacini, 1984) and tactile (Bender, 1952; Gainotti, De Bonis, Daniele, & Caltagirone, 1989; Moscovitch & Behrmann, 1994; Vallar, Rusconi, Bignamini, Geminiani, & Perani, 1994) modality. One interesting issue concerning extinction is whether the competition for selection operates across spatial representations based on different sensory modalities. More specifically, the question addressed in this study is whether the competition between left and right space representations in one modality, which is the distinctive feature of extinction patients, can be modulated (i.e., reduced or exacerbated) by the activation of an intact spatial representation in a different modality.

The prediction is that this phenomenon might occur if the two different spatial representations are coded by an integrated (visuotactile) system responsible for processing tactile stimuli and visual stimuli presented near the body (i.e., in the peripersonal space). When competition is biased in favor of the right tactile space representation, as in the case of a patient with left tactile extinction, the activation of a left visual peripersonal space might improve left tactile stimulus detection. In contrast, the activation of a right visual representation of peripersonal space might produce a deficit even in the detection of a single left tactile stimulus (cross-modal visual-tactile extinction).

Recent neurophysiological studies support this hypothesis because they document the existence of integrated visual and tactile maps of peripersonal space coded by bimodal neurons located in different brain sites (Graziano & Gross, 1994, 1995). In fact, bimodal visuotactile neurons have been found in the putamen, the frontal area 6, and in the parietal areas 7b and VIP, which respond to stimuli in particular body-related space sectors. Their receptive fields are restricted to the space around the animal's hand or face, and they typically respond less to stimuli located far from the macaque (Fogassi et al., 1992; Gentilucci et al., 1988; Graziano & Gross, 1993; Graziano, Yap, & Gross, 1994; Rizzolatti, Scandolara, Matelli, & Gentilucci, 1981). They appear ideally suited to locate a stimulus with respect to the hand, that is, in hand-centered coordinates, and not in retinal or head-centered coordinates (Graziano & Gross, 1995).

Because the hypothesis of the present study was to investigate whether a visual stimulus can modulate a tactile stimulus detection, the stimulation of the visual space around the hand seems to be the most appropriate to produce the expected modulation. This is because, due to the activity of these bimodal neurons, a visual stimulus presented near the hand should be able to activate the somatosensory representation of that hand. These predictions can be verified in patients who have tactile extinction.

Two different outcomes are expected depending on the hand (contralesional or ipsilesional) that is visually stimulated. When a tactile stimulus is delivered to both hands, the simultaneous presentation of a visual stimulus near the *contralesional hand* (e.g., left hand) should significantly improve the patient's left tactile detection. This is because the left visual stimulus enhances the damaged somatosensory representation of the left hand, and therefore, an amelioration of tactile extinction is expected. In contrast, a visual stimulus presented near the *ipsilesional hand* (e.g., right hand) should be able to activate the somatosensory representation of that hand. Due to the competition between a weak tactile representation of the left hand and an intact tactile representation of the right hand, a single left tactile stimulus might be extinguished. Preliminary findings on visuotactile extinction have been recently reported in a single-case study (di Pellegrino, Làdavas, & Farnè, 1997).

The hypothesis that the visual stimulus operates in a reference system attached to the hand, and not in other egocentric coordinates (i.e., retinal, head, or trunk-centered coordinates), also predicts a reduced interaction between vision and touch when the visual stimulus is presented far from the hand (i.e. in the extrapersonal space). For this reason, in one condition of the present study the visual stimulus was presented above the hand, at the level of patient's eyes. Moreover, another condition was run in which the visual and tactile stimuli were presented in homologous locations on the two sides of space, with the patient's right hand placed behind his or her back. Indeed, it has been reported (Mattingley, Driver, Beschin, & Robertson, 1997) that extinction can be reduced when two bilateral stimuli are presented in nonhomologous locations.

RESULTS

All patients performed at or near ceiling on trials consisting of unilateral left or right stimulus presentation. This result shows that tactile sensation was sufficient for a correct single stimulus detection and that patients rarely made spurious "both" responses. Patients almost never produced false alarms in the no-stimulation trials: This indicates that they use the "none" response when they did not detect any stimulus. Moreover, they did not erroneously report the presence of the visual stimulus when they were instructed to report only the tactile stimulus (see Conditions 5 and 6).

To test the hypothesis that a right visual stimulus may extinguish a left tactile stimulus it is necessary to compare the number of contralesional detections made in unilateral left tactile stimulus presentation with those made in bilateral stimulation (i.e., right visual stimulus and left tactile stimulus). Significantly fewer contralesional detections in bilateral trials compared to unilateral trials indicate cross-modal extinction. The percentage of correct detections made by the patients is shown in Figure 1.

A repeated-measure analysis of variance (ANOVA) with Condition as a factor (unilateral and bilateral tactile stimulation, visuotactile stimulation in peripersonal space, and visuotactile stimulation in homologous extrapersonal space and in nonhomologous extrapersonal space) revealed a significant main effect of the factor Condition ($F(4, 36) = 18.46, p < 0.0001$). Post hoc analysis showed that patients significantly more accurately detected a left tactile stimulus on unilateral than on bilateral tactile presentation [93.5% ($SD = 8$) and 39.5% ($SD = 37$) of accuracy, respectively, $p < 0.0001$]. Likewise, subjects performed better on single tactile stimulation (93.5%) than when a right visual stimulus was simulta-

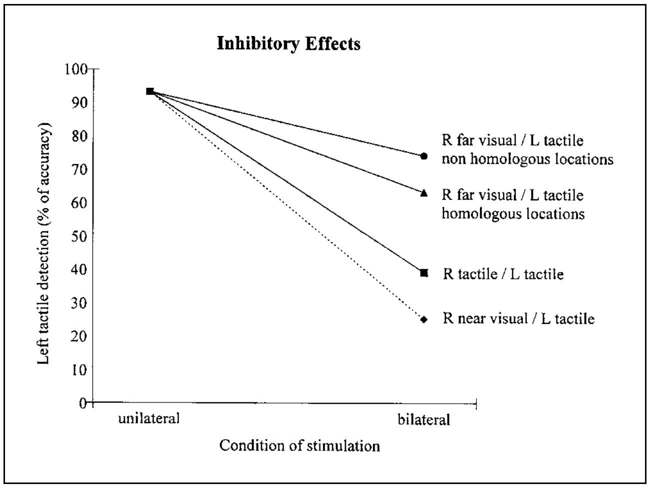

Figure 1. Inhibitory effects. Mean percentage of correct detections of the left tactile stimulus as a function of type of stimulation (unilateral or bilateral) in Condition 1 (square symbol), Condition 2 (diamond symbol), Condition 3 (circle symbol), and Condition 4 (triangle symbol). R = right hand; L = left hand.

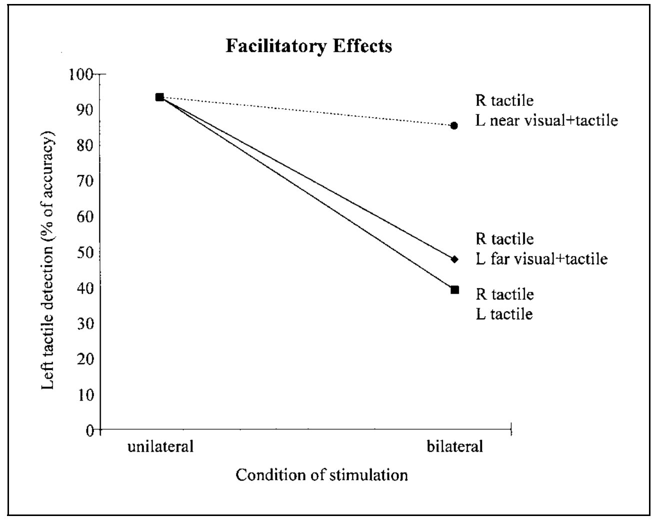

Figure 2. Facilitatory effects. Mean percentage of correct detections of the left tactile stimulus as a function of type of stimulation (unimodal or cross-modal) in Condition 5 (circle symbol), and Condition 6 (square symbol). R = right hand; L = left hand.

neously presented near the right hand [25.5% ($SD = 23$), $p < 0.0001$], in a homologous position as the left tactile stimulus [63.5% ($SD = 25$), $p < 0.006$], or at the level of the patient's eyes [74.5% ($SD = 25$), $p < 0.04$]. Moreover, it is worth noting that the cross-modal effect found when the visual stimulus was presented near the right hand (25.5%) was not significantly different from the effect found on bilateral tactile stimulation (39.5%). The difference between conditions in which the visual stimulus was presented in the homologous and nonhomologous extrapersonal space was not significant. In contrast, both conditions (63.5 and 74.5%) were significantly different from the bilateral tactile condition (39.5%, $p < 0.02$ and $p < 0.001$, respectively).

More relevant to the hypothesis of the present study, when the right visual stimulus was presented in the peripersonal space, the percentage of correct responses (25.5%) was lower with respect to the conditions in which the visual stimulus was presented in the extrapersonal space, either at the level of the patient's eyes (74.5%, $p < 0.0001$) or at the same level of the tactile stimulus (63.5%, $p < 0.001$).

To test the hypothesis that a left visual stimulus may produce an amelioration of the left tactile detection it is necessary to compare the number of left detections under bilateral tactile stimulus presentation with those made under bilateral visuotactile stimulation (i.e., bilateral tactile stimulus presentation and left visual stimulus presentation). Significantly more contralesional detections in bilateral visuotactile trials compared to bilateral tactile trials indicate cross-modal facilitation. Figure 2 shows the percentage of correct detections made in the different types of trials.

A repeated-measure ANOVA with Condition as a factor (bilateral tactile stimulation, bilateral tactile stimulation and left near visual stimulus, and bilateral tactile stimulation and left far visual stimulus) revealed a significant effect of Condition ($F(2, 18) = 10.35$, $p < 0.001$). Tactile extinction was dramatically reduced when a simultaneous visual stimulus was presented near the left hand [85.5% ($SD = 16$) of correct detections] compared to the condition in which the left visual stimulus was presented in the far space [48% ($SD = 42$), $p < 0.01$] or to the condition in which only two tactile stimuli were presented [39.5% ($SD = 37$), $p < 0.01$]. The difference between the last two conditions was not significant.

In order to elucidate whether the cross-modal extinction is influenced by the presence of visual extinction (present in 3 out of 10 patients), data were split into two subgroups and submitted to further statistical analyses. A separate ANOVA with Group (patients with only tactile extinction and patients with tactile and visual extinction) as a between-subject factor and Condition as a within-subject factor was conducted both for the inhibitory and facilitatory conditions. These analyses revealed only a significant main effect of Condition ($F(4, 32) = 14.84$, $p < 0.0001$; $F(2, 16) = 7.92$, $p < 0.004$, respectively). Neither the effect of Group nor the interaction Group X Condition were significant.

DISCUSSION

The present study provides unequivocal evidence of the existence of a visual peripersonal space centered on the hand in humans and its modulatory effect on tactile stimulus detection. In all 10 patients with a right-hemisphere lesion and reliable tactile extinction, a visual stimulus presented near the *ipsilesional hand* inhibited or interfered with the processing of a tactile stimulus delivered on the contralesional hand (cross-modal-visual-tactile extinction) to the same extent as did an ipsilesional tactile stimulation (unimodal extinction). Furthermore, a visual stimulus presented in the proximity of the *contralesional hand* improved the detection of a left tactile stimulus, that is, under bilateral tactile presentation, patients more accurately reported the presence of a left tactile stimulus when a simultaneous visual stimulus was presented near the left hand.

In contrast, weak modulatory effects of vision on touch perception were observed when a visual stimulus was presented far from the patient's hand. Indeed, cross-modal extinction was enormously reduced when an ipsilesional visual stimulus was presented at the level of patient's eyes, as well as when visual and tactile stimuli were given in symmetrical spatial locations, with the patient's right hand placed behind the back. Likewise, left tactile detection on tactile bilateral presentation did not improve when visual stimuli were presented distant from the contralesional, affected hand.

Results from animal research help to illuminate the nature of the mechanism underlying the inhibitory and facilitatory effects of vision on touch perception reported here and to clarify how such a mechanism operates to coordinate visual and tactile representations of space. Single-cell recording studies in monkeys show that parietal areas 7b and VIP, premotor area 6, and the putamen, a large subcortical nucleus forming part of the basal ganglia, appear to represent visual space near the body (Duhamel, Colby, & Goldberg, 1991; Gentilucci et al., 1988; Graziano & Gross, 1993; Graziano et al., 1994). These areas have tactile neurons that also respond to visual stimuli: Their bimodal cells have visual receptive fields that match in space the location of the tactile receptive fields and are confined in depth to a region near the animal. Because the tactile fields are arranged somatotopically, the associated visual receptive fields form a map of the visual space immediately around the body, which is thus coded in body-part-centered coordinates and not in retinal or other egocentric reference systems. Therefore, these areas provide an integrated (visuotactile) system for coding peripersonal space. As a consequence of this sensory integration, the activation of these bimodal neurons by a visual stimulus presented near the hand also activates the corresponding somesthesic representation of the hand.

Because extinction, as well as neglect, become manifest when there is a competition between two (Cohen, Romero, Farah, & Servan-Schreiber, 1994; di Pellegrino et al., 1997; Ward et al., 1994) or more spatial representations (Làdavas, Berti, Ruozzi, & Barboni 1997), the simultaneous activation of the somatosensory representation of the left hand by a tactile stimulus and of the right hand by a visual stimulus produces an extinction of those stimuli presented in the weaker representation (i.e., the left hand). Likewise, the stimulation of the visual space near the left hand results in the enhancement of the damaged (and hence weak) somatosensory representation of the left hand. This stimulation is thus able to correct the abnormal bias toward the ipsilesional hand representation and, as a consequence, left tactile extinction improves substantially.

Single-neurons studies also show that visuotactile bimodal cells are less responsive when visual stimuli are administered far from the hand, that is, in the extrapersonal space (Gentilucci et al;, 1988; Graziano et al., 1994). This neurophysiological evidence is consistent with the impressive reduction of cross-modal extinction as well as with the absence of visuotactile facilitation shown by our patients when the visual stimulus was presented far from the hand, at the level of patient's eyes.

The weak modulatory effect of far visual stimuli on touch is consistent with previous studies by Inhoff, Rafal, and Posner (1992), Làdavas, Menghini, and Umiltà (1994) and, more recently, Mattingley et al. (1997; see Table 1).

Inhoff et al. (1992) tested three right-hemisphere lesioned patients who showed consistent extinction within both visual and tactile modalities. In the cross-modal condition, there was a tactile stimulus given on the left hand and a visual stimulus presented in the extrapersonal right hemispace, at the level of patient's eyes. In this condition, which is very similar to that used in the present experiment (Condition 3), the authors found no evidence of cross-modal extinction. The findings of this study may also help to explain some of the results of a rehabilitative study previously conducted by Làdavas et al. (1994) in right-brain-damaged patients

Table 1. Summary of Results from Studies on Cross-Modal, Visuotactile Extinction

	Type of patient[a] *(%)*			*Type of stimulation*[b] *(%)*			
Study	*Tactile extinction only*	*Tactile/visual extinction only*	*Tactile/visual extinction + neglect*	*Single tactile*	*Bilateral tactile*	*Cross-modal visuotactile (near space)*	*Cross-modal visuotactile (far space)*
Inhoff et al. (1992)	0	0	100	100	0		100
Mattingley et al. (1997)	0	0	100	96	53	64	70
Present study	70	30	0	93.5	39.5	25.5	74.5

[a] Percentage of patients who manifested only tactile, only tactile/visual extinction, and tactile/visual extinction and neglect.
[b] Percentage of correct responses in different conditions of stimulation.

with both visual and tactile neglect. In this study the rehabilitation treatment was exclusively based on manipulating covert attention in the visual extrapersonal space. The results showed a clear-cut improvement of visual neglect. In striking contrast, no improvement was observed for tests that involved the tactile modality. This, again, shows that the attentional system responsible for selecting stimuli in the tactile modality is independent of the mechanism in charge of attending stimuli presented in the extrapersonal visual space. In other words, a facilitatory or inhibitory effect between different spatial representations may occur only if the neural circuits underlying these representations belong to the same functional network, as in the case of tactile and visual peripersonal space.

By using a paradigm in many ways analogous to our own, Mattingley et al. (1997) studied the cross-modal interactions between vision and touch in three neurological patients who were suffering from both visual and tactile extinction. When visual stimuli were presented far from the ipsilesional hand (Experiment 2), they found a mild cross-modal inhibitory effect (70% of correct response) that is entirely compatible with the cross-modal inhibitory effect found in the present study (74.5%) when the visual stimulus was presented at the level of the patient's eyes.

In conclusion, visual stimuli in far extrapersonal space fail to interact with touch perception (Inhoff et al., 1992; Làdavas et al., 1994; Condition 6 of the present study) or have only a mild modulatory effect (Mattingley, 1997; Condition 3 of the present study).

Furthermore, our findings are in sharp contrast with the only study in which cross-modal interaction has been investigated by stimulating the near peripersonal space (Mattingley et al., 1997, Experiment 1). When the right visual stimulus was presented near the ipsilesional hand, we found a strong cross-modal effect (25.5% of correct left tactile detections), whereas Mattingley and colleagues found only a mild cross-modal effect (65% of correct left tactile detections). In addition, this effect was not different from that found when they presented the visual stimulus far from the hand (see Table 1). However, this different pattern of results can be easily explained. In Mattingley et al.'s study, visual stimuli were always presented while the patients' view of the hand was occluded. It is known from neurophysiological findings (Graziano et al., 1994) that the responsivity of bimodal neurons to visual stimuli delivered near the hand is reduced when the hand view is blocked. This might explain the mild cross-modal effect found by Mattingley et al. in two patients and the absence of the effect in the third patient (G.V.).

To sum up, when the visual stimulus is presented in an homologous position as the tactile stimulus, but the hand is not under visual control (Mattingley et al.'s (1997) study and Condition 4 of the present study), only a mild cross-modal effect is obtained. Small effects can also be found when the hand is in view but the visual stimulus is presented far from the hand. Therefore, to induce a relevant cross-modal effect, the visually stimulated hand has to be in patient's view, and the visual stimulus has to be presented in the space surrounding the hand.

These results are entirely compatible with the visual responses exhibited by bimodal neurons, illustrated in animal work. Arm-centered bimodal neurons have been shown to respond best to visual stimuli located within 5 to 20 cm of the skin surface. These neurons can also be activated by visual stimuli located at longer distances (up to 2 m) or when the arm cannot be seen, but in these latter cases, their response is much reduced (Graziano et al.,1994). That is, bimodal neurons manifest to vary their responsiveness primarily as a function of the distance of the visual stimulus from the body surface, but their discharge is also influenced by the direct vision of the arm. Their activation is higher at closer distances and when the arm can be seen. Therefore, the strong cross-modal effect found when the visual stimulus is presented near the seen hand and the mild cross-modal effect found when the visual stimulus is presented far from the hand or near the unseen hand are fully compatible with the neurophysiological findings.

The concept of an integrated visuotactile representation of the peripersonal space does not *necessarily* predict the presence of peripersonal visual extinction in patients who have tactile extinction. Although the particular brain regions described above have tactile neurons that also respond to visual stimuli, the majority of these neurons are activated only by somatosensory stimuli (Fogasssi, Gallese, Fadiga, & Rizzolatti, 1996). The consequence of this functional organization is that the somatosensory representation is dominant over the visual representation. To find visual extinction in the peripersonal space, *all* or *most* of the brain structures containing bimodal visuotactile neurons have to be damaged by the lesion. In conclusion, the functional integrity of these areas is a necessary condition for coding peripersonal visual space and for inducing modulatory effects of vision on touch perception, as we found in the present study.

According to an alternative hypothesis, the interaction between vision and touch within peripersonal space might be due to the coordinated activation of visual and tactile maps, each coded in separate brain areas. However, this view can be refuted on the basis of the following considerations. There are many visual regions that code visual space, besides bimodal visuotactile areas, but none of them is specific for peripersonal space. Because in our study we have found that the visual stimulus is most effective when it is presented in the peripersonal space, we can rule out a prominent role of other visual areas in explaining the results described here. Moreover, the only cerebral areas responsible for mapping visual peripersonal space are those in which visual and tactile information are coded at the single neuron level (Fogassi et al., 1996). Thus, our results are better explained by the existence of an integrated visual-tactile representation of space directly coded by visual-tactile bimodal neurons.

Finally, both the inhibitory and facilitatory effects of visual stimuli on touch converge, suggesting that competition between space representations is not limited to events within the same modality but may also occur between stimuli arising from different sensory modalities. However, our study clearly indicates that cross-modal competition between vision and touch is not generalized. Visual events presented far from the ipsilesional hand (extrapersonal space) did not compete with left tactile stimuli, as did visual events presented near the hand. Thus, our study suggests the existence of an integrated system that controls both visual and tactile inputs within peripersonal space, and it shows how this system is functionally separated from the one that controls visual information in the extrapersonal space.

METHODS

Subjects

Ten patients with contralesional tactile extinction were tested in the present experiment and all of them had suffered a right-hemisphere stroke, as determined by cranial CT scan. Characteristics of patients are outlined in Table 2.

Patients were selected according to the absence of visual neglect and the presence of tactile extinction. Neglect was assessed by using three cancellation tests (Albert's lines, bell cancellation, and letter cancellation) and a line bisection task. Tactile extinction was assessed by applying a light touch on one or the other of the patient's hands, or on both hands simultaneously. Patients had to report how many stimuli had been presented (one, two, or none). When a single stimulus was detected, patient were also required to specify the hand on which it had been applied. All patients showed tactile extinction, but they performed well on single-stimulus presentation. Visual extinction was also assessed by applying visual stimuli just above the dorsal surface of one or the other of the patient's hands, and by delivering stimuli at the level of the patient's eyes. Again, patients had to report how many stimuli had been presented (one, two, or none). Only three out of ten patients showed a *mild* left visual extinction on double simultaneous stimulation, whereas their performance on single-stimulus presentation was errorless.

Materials and Procedure

Each patient sat at a table opposite the experimenter, with hands palm-down and fingers spread apart, resting approximately 40 cm apart on the table surface. Each hand was in its respective hemispace. When required, a cardboard shield (21 cm wide × 28 cm deep × 10 cm tall) was used to cover the patient's hand in order to prevent the view of the tactile stimuli applied by the experimenter. Patients were required to angle their head and eyes downward to fixate on a dot marked on the desktop at a distance of 25 cm from the front edge of the table, and aligned with the subject's midsagittal axis. In Conditions 3 and 6 the patient was asked to fixate on the experimenter's nose instead of on the central dot. Before and during each trial, the experimenter checked that the patient was maintaining fixation.

Tactile stimuli consisted of a rapid flexion-extension of the examiner's index finger (less than 1 sec), lightly touching the dorsal surface of the third finger of the patient's left hand, right hand, or both hands. Visual stimuli consisted of a single brief flexion of the experi-

Table 2. Clinical Data on Right-Brain-Damaged Patients

Patient	*Sex*	*Age*	*Years of schooling*	*Months poststroke*	*Lesion site*[a]
M.L.	F	47	5	1	P, T, I
A.F.	F	71	12	8	F, P, T
G.C.	M	66	5	3	P, T
B.C.	F	69	5	4	P, T, C, Ic
P.T.	M	65	10	1	T, Ic
A.M.	M	62	18	1	C, Pu
N.B.	F	76	13	1	P, C, Pu
B.L.	M	68	8	3	F, T
M.M.	M	72	19	36	C, Pu
A.V.	M	71	5	1	F

[a] F = frontal lobe; P = parietal lobe; T = temporal lobe; I = insula; C = caudate nucleus; Pu = putamen; Ic = internal capsule.

menter's index finger delivered just above the dorsum of patient's third finger, with the exception of Conditions 3 and 6, in which it was delivered at the level of patient's eyes, and Condition 4, in which visual and tactile stimuli were presented in homologous locations on the two sides, but the patient's ipsilesional hand was placed behind his back.

Trials were of four main types within each experimental condition: a left stimulus only, a right stimulus only, bilateral stimuli (double simultaneous stimulation), or no stimulation at all (catch trials). Catch trials were included to assess the extent to which patients guessed on trials when they felt or saw nothing. In each experimental condition there were 10 trials for each type of stimulation. Trials were given in a different pseudorandom order within each experimental condition.

Patients were tested in the six following different conditions, which were given in separate blocks (see Figure 3):

Condition 1 (Tactile Stimulation)

Tactile stimuli were applied to patient's hands, each of which was placed beneath a cardboard shield that prevented a direct view of it. In this condition, patients were told that they would feel a light touch on one or the other hand, or on both hands simultaneously, and that occasionally they would feel nothing at all. Patients were asked to respond verbally to what they had *felt* with the words *left*, *right*, *both*, or *none*. The verbal response was always accompanied by a head movement toward the left or right or both. This was done to check for a possible confusion in using spatial terms.

Condition 2 (Right Visual Near Space and Tactile Stimulation)

This condition was performed to test the presence of visuotactile extinction between right visual peripersonal stimuli and left tactile stimuli. The right hand was in the patient's view, whereas the left hand was screened with the shield. A tactile stimulus was given to the left hand and a visual stimulus was given near the right hand. In this condition, patients were told that they would *feel* a light touch on their left hand only, or that they would *see* a finger movement near the right hand only, or they would *feel* a touch on the left hand and *see* a finger movement near the right hand simultaneously. Patients were told that occasionally they would neither feel nor see anything.

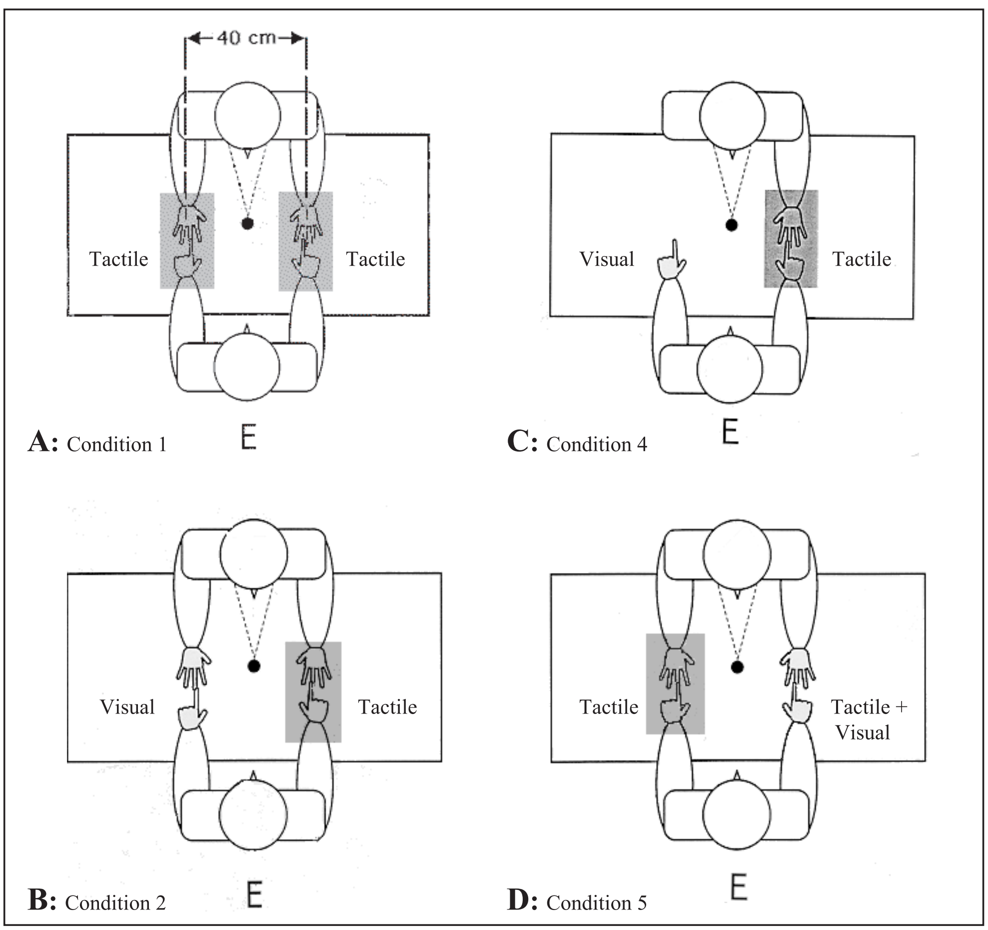

Figure 3. Schematic drawings of the experimental setting used in different conditions of the study (see text for details). The patient was seated at a table in front of the experimenter (E). Patient's hands rested on the table surface and were occluded from vision using cardboards shields (gray rectangles). The filled circle on the table indicates the point of fixation. "Visual" and "Tactile" refer to the type of stimuli applied by the experimenter in the different conditions.

Condition 3 (Right Visual Far Space and Tactile Stimulation: Nonhomologous Locations)

This condition was performed to test the presence of visuotactile extinction between right visual extrapersonal stimuli and left tactile stimuli. The right hand was in patient's view, whereas the left hand was screened with the shield. The tactile stimulus was given to the left hand, whereas the visual stimulus was presented above of the right hand, at the level of patient's eyes. In this condition, patients were told that they would *feel* a light touch on their left hand only or they would *see* a finger movement on the right side only or they would *feel* a touch on the left hand and *see* a finger movement on the right side simultaneously. As in Condition 2, they were told that occasionally they would neither feel nor see anything.

Condition 4 (Right Visual Far Space and Tactile Stimulation: Homologous Locations)

This condition was performed to test the presence of visuotactile extinction between right visual extrapersonal stimuli and left tactile stimuli located in homologous locations. The right hand was placed behind the patient's back, whereas the left hand was screened with the shield. The tactile stimulus was given to the left hand, whereas the visual stimulus was presented in a homologous location on the right side. In this condition, patients were told that they would *feel* a light touch on their left hand only or they would *see* a finger movement on the right side only or they would *feel* a touch on the left hand and *see* a finger movement on the right side simultaneously. As in Condition 2, they were told that occasionally they would neither feel nor see anything.

In Conditions 2, 3 and 4, patients were asked to respond verbally to what they had *felt or seen,* with the words *left*, *right*, *both* or *none*. As in Condition 1, verbal response was always accompanied by a head movement toward the left or right or both.

Condition 5 (Left Visual Near Space and Tactile Stimulation)

This condition was performed to test the presence of an amelioration on left tactile stimulus detection by presenting a left visual stimulus near the left hand. To this aim, the left hand was in patient's view, whereas the right hand was screened with the shield. A tactile stimulus was given to the left (or right) hand or to both hands simultaneously. The visual stimulus was given only near the left hand. In this condition, patients were told that (1) they would feel a touch on the right (or left) hand, (2) they would see a finger movement near the left hand touching the left hand *and* feel a touch on the right hand, (3) they would see a finger movement near the left hand *and* feel a touch on the right hand, or (4) they would see a finger movement near the left hand. The last two types of trials (3 and 4) were included to control for the possibility that patients erroneously report the presence of a left visual stimulus instead of a tactile stimulus. Therefore, in this condition patients were asked to respond verbally only to what they had *felt.*

Condition 6 (Left Visual Far Space and Tactile Stimulation)

This condition was performed to test the presence of an amelioration on left tactile stimulus detection by presenting a left visual stimulus in the left extrapersonal space. To this aim, the right and left hands were screened with the shield, in order to prevent the patient from viewing the tactile stimuli applied by the experimenter, which they might use as a visual cue. The tactile stimulus was given to the left (or right) hand or to both hands simultaneously. A visual stimulus was presented above of the left hand, at the level of patient's eyes. On this block of trials, one examiner applied a short-duration double tactile stimulation while a second examiner simultaneously revealed a single brief flexion of the index finger in the patient's contralesional visual field. Patients were told that they would feel a light touch on their left (or right) hand (1), or they would see a finger movement on the left *and* feel a single touch on the left (2), on the right (3), or on both hands (4). Two type of trials (2 and 3) were included to control for the possibility that patients erroneously report the presence of a left visual stimulus instead of a tactile stimulus. Therefore, in this condition patients were asked to respond verbally only to what they had *felt.*

The sequence of steps in each trial was as follows: The experimenter first checked that the patient was keeping the fixation and next, indicated the start of the trial by saying "ready" and then delivered the stimulus or stimuli appropriate for that condition. In Condition 6, the presentation of visuotactile stimuli was preceded by a third examiner saying "ready: one, two, three, four," following a 4/4 tempo. In order to keep synchronous the timing of visual and tactile stimuli, both examiners delivered the stimuli on "four," observing the rhythmic beats. Following stimulation, patients either responded spontaneously with an appropriate verbal label or, if they failed to respond, they were prompted by the experimenter to make one of the four possible responses (i.e., left, right, both, or none). No feedback was given on accuracy.

Each experimental condition was repeated twice. The order of conditions varied pseudorandomly across subjects and sessions.

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Note

1. The competition between two spatial representations may also occur when a (single) stimulus is presented in one visual hemifield while the subject is paying attention to the opposite hemifield. This is because the instruction to attend to one spatial region can cause the activation of that portion of space, which, thus, competes with the spatial location in which the stimulus has been displayed.

REFERENCES

Bender, M. B. (1952). *Disorders in perception.* Springfield, IL: Charles C. Thomas.

Cohen, J. D., Romero, R. D., Farah, M. J., & Servan-Schreiber, D. (1994). Mechanisms of spatial attention: The relation of macrostructure to microstructure in parietal neglect. *Journal of Cognitive Neuroscience, 6,* 377–387.

Critchley, M. (1949). The phenomenon of tactile inattention with special reference to parietal lesions. *Brain, 72,* 538–561.

De Renzi, E. (1982). *Disorders of space exploration and cognition*. New York: Wiley.

De Renzi, E., Gentilini, M., & Pattacini, F. (1984). Auditory extinction following hemisphere damage. *Neuropsychologia, 22,* 1231–1240.

di Pellegrino, G., Basso, G., & Frassinetti, F. (1997). Spatial extinction to double asynchronous stimulation. *Neuropsychologia, 35,* 1215–1223.

di Pellegrino, G., & De Renzi, E. (1995). An experimental investigation on the nature of extinction. *Neuropsychologia, 33,* 153–170.

di Pellegrino, G., Làdavas, E., & Farné A. (1997). Seeing where your hands are. *Nature, 338,* 730.

Duhamel, J. R., Colby, C. L., & Goldberg, M. E. (1991). Congruent representation of visual and somatosensory space in single neurons of monkey ventral intra-parietal area (area VIP). In J. Paillard (Ed.), *Brain and space* (pp. 223–236). New York: Oxford University Press.

Fogassi, L., Gallese, V., di Pellegrino, G., Fadiga, L., Gentilucci, M., Luppino, G., Matelli, M., Pedotti, A., & Rizzolatti, G. (1992). Space coding by premotor cortex. *Experimental Brain Research, 89,* 686–690.

Fogassi, L., Gallese, V., Fadiga, L., & Rizzolatti, G. (1996). Space coding in inferior premotor cortex (area F4): Facts and speculations. In F. Lacquaniti & P. Viviani (Eds.), *Neural bases of motor behavior* (pp. 99–120). London: Kluwer.

Gainotti, G., De Bonis, C., Daniele, A., & Caltagirone, C. (1989). Contralateral and ipsilateral tactile extinction in patients with right and left focal brain damage. *International Journal of Neuroscience, 45,* 81–89.

Gentilucci, M., Fogassi, L., Luppino, G., Matelli, M., Camarda, R. M., & Rizzolatti, G. (1988). Functional organization of inferior area 6 in the macaque monkey. I. Somatotopy and the control of proximal movements. *Experimental Brain Research, 71,* 475–490.

Graziano, M. S. A., & Gross, C. G. (1993). A bimodal map of space: Tactile receptive fields in the macaque putamen with corresponding visual receptive fields. *Experimental Brain Research, 97,* 96–109.

Graziano, M. S. A., & Gross, C. G. (1994). Mapping space with neurons. *Current Directions in Psychological Science, 3,* 164–167.

Graziano, M. S. A., & Gross, C. G. (1995). The representation of extrapersonal space: A possible role for bimodal, visuo-tactile neurons. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences* (pp. 1021–1034). Cambridge, MA: MIT Press.

Graziano, M. S. A., Yap, G. S., & Gross, C. G. (1994). Coding visual space by premotor neurons. *Science, 266,* 1054–1057.

Inhoff, A. W., Rafal, R. D., & Posner, M. J. (1992). Bimodal extinction without cross-modal extinction. *Journal of Neurology, Neurosurgery and Psychiatry, 55,* 36–39.

Làdavas, E. (1990). Selective spatial attention in patients with visual extinction. *Brain, 113,* 1527–1538.

Làdavas, E., Berti, A., Ruozzi, E., & Barboni, F. (1997). Neglect as a deficit determined by an imbalance between multiple spatial representations. *Experimental Brain Research, 116,* 493–500.

Làdavas, E., Menghini, G., Umiltà, C. (1994). A rehabilitation study of hemispatial neglect. *Cognitive Neuropsychology, 11,* 75–95.

Mattingley, J. B., Driver, J., Beschin, N., & Robertson, I. H. (1997). Attentional competition between modalities: Extinction between touch and vision after right hemisphere damage. *Neuropsychologia, 35,* 867–880.

Moscovitch, M., & Behrmann, M. (1994). Coding of spatial information in the somatosensory system: evidence from patients with neglect following parietal lobe damage. *Journal of Cognitive Neuroscience, 6,* 151–155.

Rizzolatti, G., Scandolara, C., Matelli, M., & Gentilucci, M. (1981). Afferent properties of periarcuate neurons in macaque monkeys: II. Visual responses. *Behavioral and Brain Science, 2,* 147–163.

Vallar, G., Rusconi, M. L., Bignamini, L., Geminiani, G., & Perani, D. (1994). Anatomical correlates of visual and tactile extinction in humans: A clinical CT scan study. *Journal of Neurology, Neurosurgery and Psychiatry, 57,* 464–470.

Ward, R., Goodrich, S., & Driver, J. (1994). Grouping reduces visual extinction: Neuropsychological evidence for weight linkage in visual selection. *Visual Cognition, 1,* 101–129.