

Coding of Spatial Information in the Somatosensory System: Evidence from Patients with Neglect following Parietal Lobe Damage

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Abstract

■ Unilateral parietal lobe damage, particularly in the right cerebral hemisphere, leads to neglect of stimuli on the contralateral side. To determine the reference frame within which neglect operates in the somatosensory system, 11 patients with unilateral neglect were touched simultaneously on the left and right side of the wrist of one hand. The hand was tested in

both the palm up and the palm down position. Patients neglected the stimuli on the side of space contralateral to the lesion regardless of hand position. These results indicate that point-localization in the somatosensory system is accomplished with respect to a spatially defined frame-of-reference and not strictly with respect to somatotopically defined coordinates. ■

INTRODUCTION

Individuals with damage to the right parietal lobes often suffer from hemineglect, a dramatic attentional disorder in which information on the left side is ignored (Bisiach & Vallar, 1988; Critchley, 1953; Heilman, Watson, & Valenstein, 1985; Mesulam, 1981). In surveying the environment, patients with hemineglect do not notice objects on the left; in reading, they may ignore the left side of a page or even the left half of a word; in eating, they may leave the food on the left side of the plate untouched; in hearing, they attend mostly to auditory input from the right, ignoring the speaker on the left; and in personal care, they may not shave or bathe the left side of the body and may dress only the right side. At issue is what constitutes the "left side," that is, with respect to what frame of reference is the left side defined? The answer to this question is important for understanding the role of the parietal lobe in spatial mapping and in attention. Although this question has been addressed in vision, there have been no studies to determine whether common principles apply to modalities such as somatosensation whose functional organization may be different from that of vision.

A number of interpretations have been offered to explain why neglect occurs on the side opposite the lesion. One view is that hemineglect is defined with respect to coordinates of the sensory receptive fields and is associated with the contralateral sensory loss that usually accompanies the parietal lobe lesion (Bay, 1953; Denny-Brown, & Chambers, 1958). Put simply, patients ignore

stimulation of the sensory surface projecting to the lesioned hemisphere. Recent work in vision has refuted the notion that this view can account for all aspects of neglect. A number of investigators have shown that what is neglected is not necessarily the stimulus in the left visual field, but rather the left-most item of a set of stimuli, even when all of them are presented to the intact, right visual field. With regard to objects and words, it is the left side of each that is neglected rather than the field in which it appears (Behrmann, Moscovitch, Black, & Mozer, 1990; De Renzi, Gentilini, Faglioni, & Barbieri, 1989; Ellis, Flude, & Young, 1987; Gazzaniga, & Ladavas, 1987; Kinsbourne, & Warrington, 1962; Ladavas, Petronio, & Umiltà, 1990; see also Caramazza, & Hillis, 1990 for comparable effects following left hemisphere lesions). These observations led to the conclusion that neglect is not defined solely in terms of sensory coordinates but occurs within a more abstract frame of reference that assigns spatial coordinates to sensory stimuli, scenes, and objects that map onto it.

Because neglect can occur in all sensory modalities (Bisiach, & Vallar, 1988; Critchley, 1953; Heilman et al., 1985; Heilman, Bowers, Valenstein, & Watson, 1987; Vallar, Bottini, Rusconi, & Sterzi, 1993), it is important to determine whether similar principles apply to modalities that have properties different from vision. Because vision relies on sense receptors that code spatially distant information about the external world, it seems reasonable that the visual system adopts a nonsensory spatial frame of reference. Somatosensation, on the other hand, is concerned with detecting stimulation on the body sur-

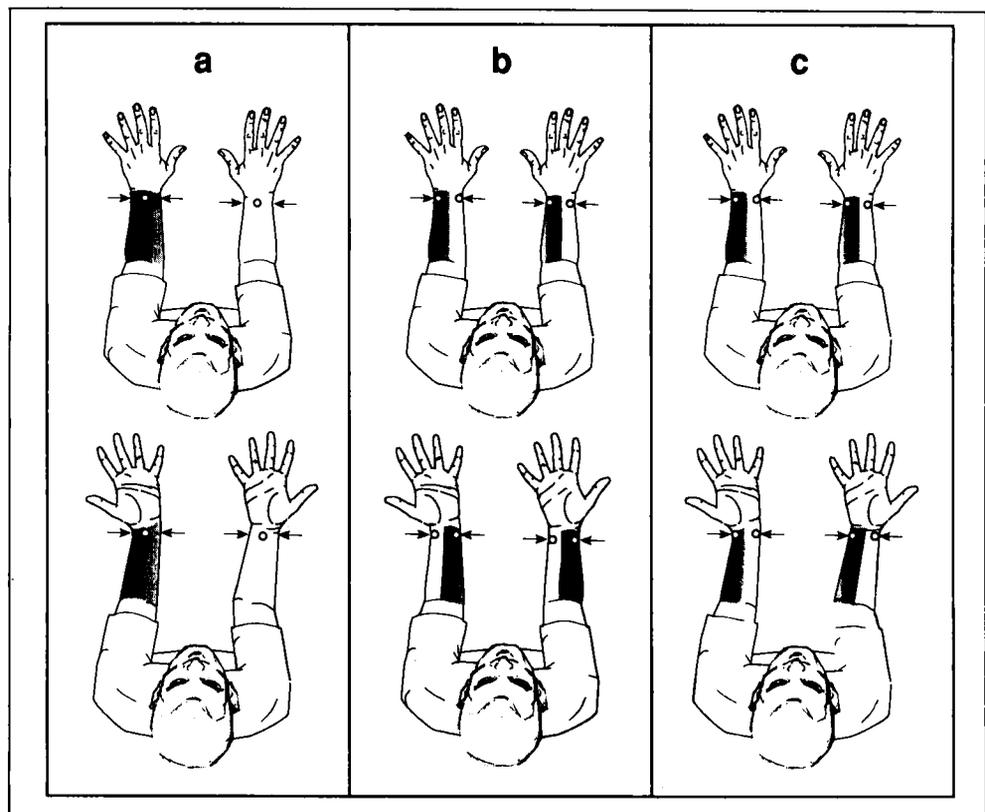
face and in monitoring its location. When left hemineglect occurs in the tactile modality, do individuals ignore the “left” as defined with respect to a sensory receptor surface (somatotopic) or also as defined with respect to a higher-order spatial frame-of-reference as in vision?

To answer this question, we tested for tactile neglect in patients with parietal lobe lesions using the procedure of double simultaneous stimulation (Critchley, 1953; Feinberg, Haber, & Stacey, 1990; Kolb, & Whishaw, 1990; Mesulam, 1981, 1985). In this procedure, the individual is touched lightly, and simultaneously, at two locations. Although the person with hemineglect usually can sense and locate a single touch accurately even on the affected side, he or she has difficulty when two stimuli are involved. The person often reports only the stimulus on the right, extinguishing or ignoring the stimulus on the affected, left side. The standard method for demonstrating left-sided neglect is to present stimuli to the left and right sides of the body’s somatosensory midline (Fig. 1a; but see Feinberg et al., 1990 for variations). In this testing condition, however, sensory and higher-order, spatial frames of reference are aligned with each other, making it impossible to distinguish between them. In addition, it is not clear whether neglect arises from competition for a central attentional mechanism or whether it occurs because the stimulus on the left is effectively weaker than the one on the right owing to the contralateral sensory loss that usually accompanies the parietal lobe lesion.

To decouple the somatotopic and spatial frames of reference, we stimulate in two adjacent locations on the same side of the midline: two points on either side of a single wrist (Fig. 1b, or c). Testing was conducted in two conditions: with the palm up and with the palm down. By stimulating two locations on the same side of the midline, it becomes possible to determine whether neglect in the somatosensory system occurs with respect to somatotopic, or higher-order, spatial, frames-of-reference. By confining both stimuli to a single limb, this procedure also ensures that sensation is comparable at both locations. Because most patients have some sensory loss affecting the limb contralateral to the lesioned hemisphere, we usually tested only the ipsilesional hand. In the rare person in whom sensory loss was minimal, we tested both hands. Each hand was tested separately.

If the frame-of-reference hypothesis is defined with respect to the somatosensory midline, neglect should be observed only when the affected hand, the one opposite the lesioned hemisphere, is stimulated (Fig. 1a). An alternative somatotopic sensory hypothesis might admit that extinction could occur on either hand, but that it would be recorded in the same sensory location, say the point on the wrist near the thumb, irrespective of the rotated position of the hand (Fig. 1b). By contrast, if neglect occurs with respect to a higher-order frame-of-reference, then extinction should occur on the same side of space, say the “left” of each hand, regardless of the particular sensory location that occupies that position (Fig. 1c). For the right hand, this would be the thumb

Figure 1. Touch is applied at the circles. Shaded area indicates the region where the stimuli are neglected as predicted by three different hypotheses: (a) Neglect is somatotopically defined with respect to the sensory surface projecting primarily to the contralateral, lesioned hemisphere. (b) Neglect is defined with respect to the sensory position of one side of the hand (e.g., the side nearest the thumb on the right hand, regardless of hand orientation). (c) Neglect is defined with respect to a higher-order spatial frame-of-reference that is invariant across hand orientations (e.g., the thumb side of the right hand when the palm is down but the little finger side when the palm is up).



side when the palm is down but the little finger side when the palm is up. The reverse would hold for the left hand.

RESULTS

The results (Table 1) for the right hand of the 10 patients with left-sided neglect due to right parietal lesions are as follows: Neglect occurs predominantly on the left side without regard to the hand that is stimulated or its position. This pattern held for all 10 patients and was confirmed in a two-way analysis of variance with hand position (palm up/palm down) and location (thumb/little finger) as within-subject variables. Whereas the hand by location interaction was significant [$F(1,9) = 18.8, p < 0.01$], neither hand position [$F(1,9) = .76, p > 0.10$] nor location [$F(1,9) = 1.04, p > 0.10$] alone reliably predicted neglect. Neglect of the left side independent of hand position was also observed on the left wrist of the single patient with preserved sensation of that arm. All these patients performed normally in the unilateral stimulation condition: eight scored perfectly, one made two errors in the palm up condition and two made one error in each hand position.

The one patient with right neglect displayed a similar pattern but with neglect for the right of space. Indeed, this subject's inattention to the right was so marked, that when his right hand was stimulated unilaterally, he localized all stimuli to the left even those that were presented on the right side of the wrist. The tendency to localize erroneously stimuli on one side to the other is known as *allaesthesia* and is not uncommon during recovery from neglect (Joanette & Brouchon, 1984; Kawamura, Hirayama, Shinohara, Watanabe, & Sugushita, 1987; see also Halligan, Marshall, & Wade, 1992). Taken together, these results are interpreted as showing that the stimulus on the contralesional side as spatially defined is neglected independent of hand position.

To confirm that these patients are capable of detecting two simultaneously presented tactile stimuli when they do not fall along a left-right (horizontal) continuum, we presented two simultaneous stimuli vertically along the

midline of the arm with one stimulus at the wrist and the second two inches away towards the elbow.¹ This was done in the palm up and palm down condition as before. The four patients who were available for testing in this condition could detect both stimuli perfectly in both hand positions.

DISCUSSION

The critical finding is that the contralesional side of space is neglected independent of hand position. These results indicate that in the somatosensory system, as in the visual system, hemineglect is defined with respect to a higher-order spatial frame-of-reference and not only (if at all) with respect to a sensory, somatotopic frame-of-reference.

The dominance of higher-order over sensory frames-of-reference is also observed in olfaction (Bellas, Novelly, Eskenazi, & Wasserstein, 1988; Mesulam, 1981; Bellas, Novelly, & Wasserstein, 1989). Unlike the visual and tactile system whose primary sensory projections cross to the contralateral hemisphere, projections from the nostrils are uncrossed. Yet here, too, in a study of bilateral simultaneous extinction, patients with right parietal lesions were much more likely to ignore odors directed to the left than to the right nostril.

Upon reflection, it should not be surprising that a higher-order frame-of-reference determines the spatial coordinates that guide attention, and, by implication, point localization in all sensory modalities, even the tactile one. Sensory stimulation informs the organism about its environment so that it can act appropriately. If a limb is stimulated, the organism may wish to move toward the source of stimulation or away from it. Because under natural conditions the position of the limb at the time of stimulation is unpredictable, the only way the organism can respond effectively is by coding the input, and directing its responses, with respect to a higher-order spatial frame-of-reference that maps the action space accurately.

Having determined that neglect occurs within a higher-order spatial frame-of-reference, investigators have

Table 1. Mean (SD) Neglect Errors (Maximum = 10) during Simultaneous Tactile Stimulation of the Left and Right Sides of the Same Hand

Patients	Palm Down		Palm up	
	Thumb	Little finger	Little finger	Thumb
Right parietal lesions/left neglect				
Right hand ($n = 10$)	4.2 (1.9)	1.2 (1.6)	4.9 (3.1)	1.2 (1.3)
Left hand ($n = 1$)	1.0	9.0	1.0	8.0
Left parietal lesions/right neglect				
Right hand ($n = 1$)	1.0	10.0	1.0	8.0
Left hand ($n = 1$)	8.0	2.0	9.0	1.0

turned to the more difficult problem of determining which of a number of possible frames of reference are involved. Several candidates have been proposed. Among them are viewer-centered frame of reference, which is defined in terms of either gravitational coordinates (Ladavas, 1987) or coordinates centered in the body midline (Karnath, Schenkel, & Fischer, 1991); environment-centered, which is defined in terms of coordinates of the environment that is being attended (Calvanio, Petrone, & Levine, 1987; Farah, Brunn, Wong, Wallace, & Carpenter, 1990); or object-centered, which is defined in terms of spatial coordinates intrinsic to the object that is being attended (Caramazza & Hillis, 1990; Driver & Halligan, 1991; Grabowecky, Robertson, & Treisman, 1993). Sometimes, hemineglect occurs with respect to a number of frames of reference that operate concurrently and whose influences are detectable when decoupled. For example, by tilting asymmetrical letters such as "B" 90° from their normal orientation, Behrmann and Moscovitch (1994) showed that in patients with right hemisphere damage, left neglect occurs within both viewer/environment-centered and object-centered frames of reference. They found that patients neglect the straight edge of "B" regardless of orientation (object-centered) as well as the part of the "B" that falls on the left with respect to the patient or environment (viewer/environment-centered).

As Stein (1992) notes, the rich multimodal sensory and motor projections to and from the parietal lobe provide it with the requisite connections for mapping space as well as for directing action within it. Thus, the parietal lobe is well-suited to be at the center of an attentional network of structures² that are involved in remapping sensory coordinates onto higher-order, spatial frames-of-reference (Duhamel, Colby, & Goldberg, 1992). These transformations enable the organism to act effectively in a world where spatial relations are defined with respect to coordinates external to the organism.

METHOD

Subjects

Patients with parietal lesions were screened for evidence of hemineglect using the Sunnybrook Battery for Neglect (Black, Vu, Martin, & Szalai, 1990), which includes a drawing/copying task, line bisection, figure cancellation, and line cancellation. Performance on this battery has been standardized on normal control subjects and points are assigned indicating the degree to which performance differs from the norm (e.g., on line cancellation, 2 points is assigned for each omitted line). A cumulative neglect score is obtained across the four tasks and a score above 5 exceeds the normal cutoff. Scores ranging from 6 to 40 reflect mild to moderate neglect, while scores greater than 40 are indicative of severe neglect. Patients were also screened for tactile extinction using the procedure of double simultaneous stimulation (Critchley, 1953; Feinberg et al., 1990; Vallar et al., 1993).

Eleven patients who met both criteria (neglect and tactile extinction) were chosen, 10 with left-sided neglect following CT-scan documented right parietal lesions and one with right-sided neglect who had a large left parietal lesion and a smaller, nonparietal lesion on the right. All patients sustained a middle cerebral artery infarct. The lesions varied in size and depth—in the extreme case, the lesion extended from the occipital cortex to the motor cortex while in other cases, the lesion was more circumscribed. These patients, seven of whom were male and four female, constituted approximately 50% of the patients whom we screened. The patients ranged in age from 56 to 81 with a mean of 63 and with an average of 11.7 years of education. All patients were right-handed and consented to participate in this study. Four patients were classified on the Sunnybrook Battery for Neglect as severe (mean score 49) and the remaining seven as mild to moderate (mean score 23).

Procedure

Stimulation was applied with cotton wool or with light finger touch to points on either side of the wrist. For each hand position, there were 30 stimulation trials that were presented in a predetermined random order: 10 on each side separately and 10 simultaneously on both sides of the wrist (see Fig. 1b and c). The position of the hand during the initial test was counterbalanced across subjects. The individual, with eyes closed and arm extended, sat opposite the experimenter. Upon feeling a touch, the individual indicated verbally or by gesture (the choice was left to the subject) whether he or she felt the stimulus on the thumb side, little finger side, or both sides. The verbal response could refer to the fingers (thumb or little finger) or the patient could say "inside" or "outside" but never the words "left" or "right." No feedback was given during the testing procedure, which lasted about a half hour. All patients were tested on the arm ipsilateral to the lesion. In only two patients, one with left neglect and the one with right neglect, was contralateral sensory loss sufficiently minimal to permit testing of both arms.

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Notes

1. We thank M. Marsel Mesulam for suggesting this control procedure.

2. We observed a similar pattern of performance in a patient with hemineglect caused by lesions of the right frontal lobe, a structure that is part of the attentional network; for discussion of attentional circuits see Heilman, Watson, and Valenstein (1985) and Mesulam (1981, 1990).

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