

Coding of Far and Near Space in Neglect Patients

Anna Berti,^{*,1} Nicola Smania,[†] and Alan Allport[‡]

^{*}*Dipartimento di Psicologia, Università di Torino, Torino, Italy,* [†]*Ospedale Borgoroma, Verona, Italy;* and [‡]*Department of Experimental Psychology, University of Oxford, Oxford, United Kingdom*

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Far (extrapersonal) and near (peripersonal) spaces are behaviorally defined as the space outside arm-reaching distance and the space within arm-reaching distance. Animal and human studies have shown that this behavioral distinction corresponds in the brain to a composite neural architecture for space representation. In this paper we discuss how the activation of the neural correlates of far and near space can be modulated by the use of tools that change the effective spatial relationship between the agent's body and the target object. When subjects reach for a far object with a tool, it is possible to show that far space is remapped as near. We shall also argue that space remapping may not occur when far space is reached by walking instead of using a tool. © 2001 Academic Press

INTRODUCTION

Neurophysiological studies in animals have shown that near and far space (behaviorally defined as the space within and beyond arm's reach) are coded in different brain areas and by different neural mechanisms. Area 8 of the monkey frontal lobe, implicated in the coding of saccades (e.g., Bruce and Goldberg, 1985), has been proposed to be involved in far space representation. Colby *et al.* (1996) showed that neurons in area LIP (that is richly connected with, and physiologically similar to, area 8) may be another neural substrate for the representation of far space in monkeys. Near space, on the other hand, seems to be represented in frontal area 6 and in the rostral part of the inferior parietal lobe, area 7b (Leinonen *et al.*, 1979) and area VIP (Colby *et al.*, 1993; Duhamel *et al.*, 1997). While far space neurons are primarily visual, neurons coding peripersonal space (i.e., the space in which there can be direct interaction between the object and the body) often have bimodal receptive fields, visual and tactile.

¹To whom correspondence and reprint requests should be addressed at Dipartimento di Psicologia, Università di Torino, Via Lagrange, 3, 10123 Torino, Italy. Fax: 39 011 549653. E-mail: berti@psych.unito.it.

Some “peripersonal” neurons fire both when a tactile stimulus is delivered to the animal's skin and when a visual stimulus is presented in the space *near* the part of the body where the tactile field is located (Fogassi *et al.*, 1996; Gentilucci *et al.*, 1988; Graziano and Gross, 1995; Graziano *et al.*, 1994). The representation of peripersonal space seems therefore to rely on an integrated bimodal system of stimulus representation.

A practical consequence of this distributed neural system for space representation is that damage to a single brain area can cause, in monkeys, unawareness for stimuli presented in a specific and restricted sector of space (Rizzolatti and Gallese, 1988). For instance, ablation studies, have shown that lesions of monkeys' frontal eye-fields (area 8) cause inattention for stimuli presented contralateral to the brain damage (Latto and Cowey, 1971) especially in *far* space (Rizzolatti *et al.*, 1985). By contrast, lesions of area LIP can cause inattention for stimuli presented near the monkeys' body and face (Rizzolatti *et al.*, 1983).

CODING OF FAR AND NEAR SPACE IN HUMANS

The first question we can ask is whether, also in humans, space awareness is achieved by the joint activity of many different brain areas coding different spatial attributes of external stimuli. If so, one may advance the hypothesis that a discrete lesion of the human brain might impair awareness for stimuli presented in a specific sector of space, as in monkeys. Neglect patients, who show impairments in the detection of stimuli contralateral to the brain damage, similar although more complex, than those described in monkeys, are usually tested in near peripersonal space. However, based on the behavior of the patients in everyday life, it has often been assumed that unawareness of stimuli is not limited to the space surrounding the body, but extends to include all the space visible by the subject. This clinical assumption seemed to be confirmed by Pizzamiglio *et al.* (1989), who investigated the possibility of a dissociation between near and far space neglect in a group of right-brain damaged patients. Using a purely perceptual task, they did not

find any evidence in favor of the existence of such a dissociation. Halligan and Marshall (1991), however, presented the first evidence for a possible distinction between near and far space coding in man. They described a patient with a marked neglect in a line bisection test, when the task was executed in near space by means of either an ordinary pen or a projection light-pen. However, when the patient was asked to bisect lines in far space by means of a projection light-pen, neglect was greatly reduced or even disappeared. This finding demonstrated, for the first time in humans, that unawareness for stimuli can be restricted to a specific sector of space. The finding of the opposite dissociation (more severe neglect in far space than in near space) confirmed that, also for humans, far and near space can be separately coded by the brain (Cowey *et al.*, 1994, 1999; Vuilleumier *et al.*, 1997). Interestingly, a recent PET study has confirmed the anatomical distinction between near and far space coding in humans (Weiss *et al.*, 2000).

The studies just reviewed demonstrate that neglect in man shows aspects that are similar to those described in monkeys, especially in tasks that are not purely perceptive. In the experiment by Pizzamiglio *et al.* (1989), where neglect for both far and near space was always present, the task did not require any kind of explicit movements to be accomplished. The judgement about the stimuli could be given even without (or with minimal) ocular movements. On the contrary, in the studies reported by Halligan and Marshall (1991), Cowey *et al.* (1995), and Vuilleumier *et al.* (1997), the task always involved a visuo-motor skills that might be expected to map onto a spatial representation dedicated to actions typically performed when the stimuli are in far or near space respectively. In other words, one may advance the hypothesis that the activation of near and far space representation (and consequently, the awareness for stimuli presented in definite sectors of space) is not merely dependent upon the computation of the reaching distance, but may, at least to some degree, be modulated by specific actions performed in near or far space.

SPACE REPRESENTATION AND ACTION

In everyday life, both animals and humans need to reach for objects around them. Depending on the distance away of a given object, different types of action are afforded. For instance, if the object of interest is close to the body (in near/peripersonal space), manual reaching may be performed. If the object is beyond manual reach (in far/extraperpersonal space) two different possibilities are available. The subject can use a tool to reach for a far object, or he/she can reach the far object by locomotion. To accomplish such tasks successfully, the brain must (a) compute the distance of the object from the agent's body correctly and (b) activate

the maps for near and far space representations appropriate to the computed distance. A question we can ask is how the brain establishes what is far and what is near. One possibility is that far and near are exclusively distinguished by the distance that the hand can reach in space. If this is the case, the distinction between far and near space would be based solely on depth computation (here intended as the extraction of the visual parameters necessary for the processing of the objects distance). When the distance between the body and the stimulus is perceived as such that the hand can reach the stimulus, then the stimulus is coded as near (near space maps are activated). When the stimulus is perceived as lying outside the reach of the hand, then it is coded as far (far space maps are activated). The distinction between near and far space would be, within one subject, very neat and rigid. Another possibility is that coding of spatial positions is a more dynamic operation, not only related to the computation of the absolute distance between the body and the stimulus, but also related to the execution of specific actions in space. Iriki *et al.* (1996) showed, in monkeys, that the activation of far and near space maps can be influenced by the use of tools when the action modifies the *spatial relation* between the body and the object. They found in the monkey parietal lobe bimodal neurons that coded the schema of the hand, similar to those studied by Rizzolatti and co-workers (Fogassi *et al.*, 1996; Gentilucci *et al.*, 1988) and by Graziano *et al.* (1994). As already discussed, these neurons fire when a tactile stimulus is delivered to the monkey's hand and when visual objects are presented near the hand tactile receptive field. The most striking characteristic described by Iriki *et al.* (1996) was that the visual receptive field of the bimodal neurons could be modified by a purposeful action. Indeed, when the monkeys reached for far objects with a rake the visual receptive field was enlarged to include the entire length of the rake and to cover the expanded accessible space. The authors explained their results by postulating that during the reaching movement the tool was assimilated to the animal's hand, becoming part of the hand representation (e.g., Aglioti *et al.*, 1996). The space now reachable by the prolongation of the hand was enlarged, including part of what had previously been far space, and the spatial relation between the body and the object is modified by the action of reaching-with-a-tool. As a consequence, far space was remapped as near and the neurons that fired for near space also fired when what had previously been coded as far space was reached by the rake.

This modulation of space coding can also be shown in humans. We asked a group of right brain-damaged patients with neglect, a group of right brain-damaged patients without neglect, and a group of neurologically intact subjects to perform a line bisection task both in near (lines placed 50 cm from the body) and far (lines

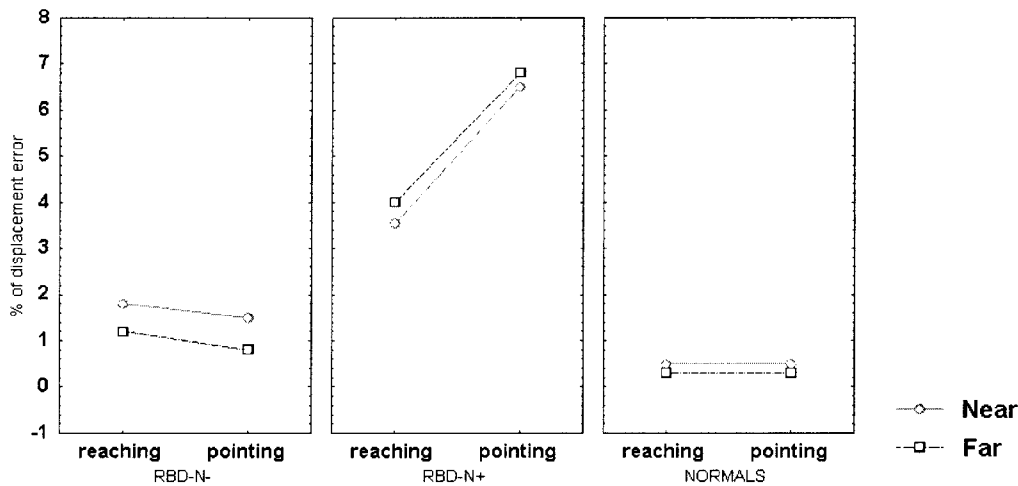


FIG. 1. Bisection performance of a group of seven right-brain-damaged patients without neglect (RBD-N-), a group of eight right-brain-damaged patients with neglect (RBD-N+), and a group of nine neurologically intact subjects (normals).

placed approximately 1 m from the body) space. Line length in near space could be either 10 cm (short lines) or 20 cm (long lines). Line length in far space was corrected for the visual angle and was either 20 cm (short lines) or 40 cm (long lines). In this way, short lines in near and far space and long lines in near and far space covered the same angle at the retinal level. In near space, the patient had to bisect the line either by touching the midpoint of the line with the index finger of the right hand (reaching modality) or by indicating the midpoint of the line by means of a projection light-pen (pointing modality). In far space, the patient had to bisect the lines either by using a 100-cm stick (reaching modality) or by means of a projection light-pen (pointing modality). The dependent variable was the displacement errors in mm. Line length did not show any significant effect on performance and the results are therefore presented collapsed for line length. As shown in Fig. 1, both right brain-damaged patients without neglect and normals were accurate in indicating the line midpoint both in far and near space, in the pointing and in the reaching modality. The neglect patients as a group did not show any dissociation in the performance carried out in near and far space. They only showed a significant rightward displacement in all conditions, with pointing being, if anything, more impaired than reaching. As in the study of Pizzamiglio *et al.* (1989), the tendency in the group of neglect patients was to show approximately the same grade of neglect both in near and far space. No differential action modulation on near versus far space representation was manifest.

However, with the same paradigm, Berti and Frassinetti (2000) showed in a right brain-damaged patient (with a dissociation between near and far space neglect) that, when the cerebral representation of body space was extended to include objects or tools used by

the subject for a purposeful action, the space previously mapped as far was then treated as near, like in monkeys. Patient PP had a clear neglect in near space in many different tasks including line cancellation, reading and line bisection. Line bisection in near space was affected by neglect both when the patient had to perform the task by a reaching action with the index finger of the right hand, and when she had to point with the projection light-pen. When the lines were positioned far from the body neglect was much less severe or even absent when tested using the projection light-pen (see Fig. 2). This result is very similar to that described by Halligan and Marshall (1991) and, again, shows that far and near space can be differently affected by brain damage. However, in Berti and Frassinetti's experiment, the patient was also asked to bisect lines in far space using a stick through which the patient could reach the line. Under this condition, neglect appeared also in far space and was as severe as neglect in near space. We explained this result by reference to the neurophysiological data reported by Iriki *et al.* (1996): as in monkeys, the use of a tool extended the body space, thus enlarging the peripersonal space up to include all the space between the patient's body and the stimulus. Far space was, as a consequence, remapped as near—i.e., the representation for near space coding was activated. Because near space representation was affected by neglect, neglect became manifest also in far space.

Having shown that the activation of space representation can be modulated by actions that change the subject's effective spatial relationship to a target object, another question we asked is whether a similar remapping occurs also when far space is reached not by using a tool but by locomotion (Berti *et al.*, submitted). Neglect patients and brain-damaged patients without neglect were asked to perform two bisection tasks: one

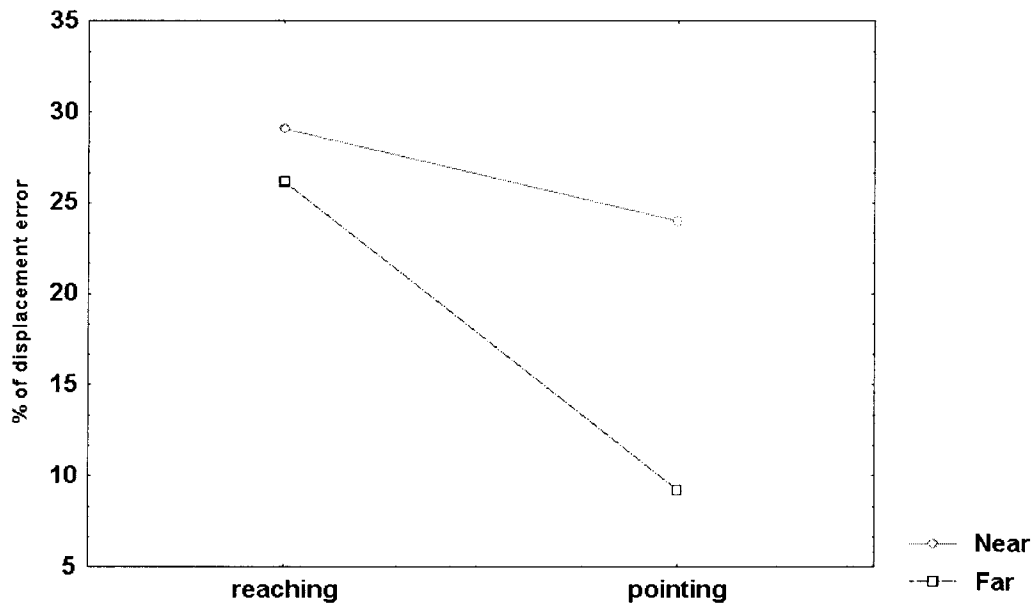


FIG. 2. Patient PP' bisection performance as a function of space and modality. Reproduced, by permission of MIT Press, from Berti and Frassinetti (2000).

was a line bisection task to be accomplished using a projection light-pen, the other was a bisection of a doorway by walking through it. The two tasks were performed at (or starting at) three different distances from the target (3, 1.5, and 0.5 m). We found three neglect patients who showed more severe neglect in far than in near space. Based on this observation, we predicted that if the representation of space is updated during walking, our neglect patients should activate an impaired representation at the beginning of each walking path and a less impaired, or unimpaired, representation toward the end of it, in the two longer distance conditions. Therefore, their walking trajectories should deviate at the beginning of each path, especially with the most distant starting point, but as they approached the doorway, with the activation of better preserved space representations, the walking trajectories should be corrected. As a consequence, the passage through the doorway (i.e., the actual displacement error) should be *similar from all three starting point conditions*. On the contrary, if space is not updated, then the first representation that is activated, at the beginning of each path, will be the one responsible for the final bisection performance. Therefore, if spatial neglect is more severe in far than in near space, we should expect to find worse performance with the starting point in far space (activation of far space) than with the starting point in near space.

As already mentioned, in the pointing modality, the three neglect patients showed a more severe neglect in far than in near space. In the walking task these patients also tended to cross through the doorway to the right of its objective midpoint and with a greater devi-

ation when the starting point was in far space. According to our prediction we interpreted these results as evidence that—at least for short, linear trajectories—these patients did not up-date the spatial position of a far target object during locomotion. The location of the far object is coded at the beginning of the movement, and the error in the bisection computation is generated within the first representation that is activated.

Although the absence of space remapping in the locomotion task might be due to neglect patients' reduced attentional/representational capacities, it can also be explained by the necessity (both in brain damaged people and in normals) of constructing a stable representation of the spatial position of the object that otherwise would be continuously changed as the subject passes, during walking, across different sectors of space. In the case of tool use, on the contrary, the switch in spatial coding occurs *before* the action begins, *once the brain has coded the tool as an extension of personal space*. It is reasonable to suppose that updating during walking may become necessary for distances greater than those we used, or when a rapid change in some characteristic of the target, or a perturbation in the walking trajectory, is introduced *during* the subject's walking.

CONCLUSIONS

Neuropsychological and neurophysiological studies have shown many similarities between animals and humans in the brain mechanisms of space coding. Both single cell recordings and lesion studies have revealed

that the neural systems dedicated to space representation and spatial cognition are implemented in a distributed network where discrete brain areas are devoted to the coding of the different spatial attributes of the stimulus (Rizzolatti and Berti, 1993). This network is not simply based on perceptual operations, but is greatly modulated by the programming of purposeful actions that modify the spatial relation between the subject and the external world. Purposeful actions seem to have effects on the activation and modulation of space representations especially when there is a change in the spatial extension of the agent's body, as in tool using.

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