

SPATIO-MOTOR CUEING IN UNILATERAL LEFT NEGLECT: THE ROLE OF HEMISPACE, HAND AND MOTOR ACTIVATION

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(Received 20 May 1991; accepted 24 January 1992)

Abstract Reported beneficial effects of left arm activation on neglect are experimentally examined. The present study of a subject with left visual neglect compared left hand finger movement with an instruction to visually anchor perception on the left arm during letter cancellation. Only the finger movements significantly reduced neglect. Another comparison was between "out of sight" finger movements of the left hand in left and right hemispace, respectively. Only left hemispace "blind" finger movements significantly reduced neglect compared to the standard condition. Thirdly, blind left finger movements in left hemispace were compared with passive visual cueing (reading a changing number) and again it was found that only the finger movements reduced neglect. Finally, right finger movements in left hemispace were compared with left finger movements in left hemispace: only the latter reduced neglect. The implications of these findings for theory and therapy of neglect are discussed.

INTRODUCTION

Contralesional limb activation in visual neglect

A NUMBER OF STUDIES have shown that left visual neglect or allesthesia may be ameliorated if target stimuli are detected or manipulated by the left hand (i.e. the hand opposite the lesion) [4, 7, 8]. HALLIGAN *et al.* [5] attributed this effect to spatio-motor cueing, however, as they found the effect to disappear during line-bisection if the subject was required to begin the task with the left hand positioned on the right.

This hypothesis stands in contrast to the view which might be derived from RIZZOLATTI and his colleagues (e.g. Refs [11] and [12]), who propose that perception and action are so closely integrated that activation of one system might plausibly lead to "recruitment" of the other.

While the recruitment hypothesis might predict improvement after left hand activation (in the case of left neglect) in either hemispace, the cueing hypothesis predicts improvement after movements by either hand on the left side. The cueing hypothesis also predicts that visual cueing to the left should improve performance.

The present study systematically examines these rival hypotheses in the following series of experiments.

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SUBJECT

The subject was a previously fit 62-year-old right-handed motor mechanic who had suffered a right CVA on 8 February 1991, leaving him with a left hemiparesis and a left homonymous hemianopia. On neurological assessment 17 days later, he showed 0.5 power in his left arm, 4.5 in his left leg, with normal power in his right limbs. He showed decreased sensation in his left arm and leg. He was fully oriented for time, place and person, but showed clear left visual neglect of which he was aware and also distressed by it. He also showed sensory neglect on his left side. His Mini-Mental State score was 28/30. A CT scan showed multiple cerebral infarcts in the region of the right middle cerebral artery.

Neuropsychological assessment revealed severe left visual neglect, as measured by the "conventional" items of the Behavioural Inattention Test (BIT), where he scored in the severe neglect range with 54 out of a maximum of 146. His Logical Memory (Revised Wechsler Memory Scale), immediate and delayed, were both in the normal range for his age (57 and 64th percentiles, respectively), and he showed no significant perseveration on the Nelson version of the Wisconsin Card Sorting Test (where the cards were aligned vertically rather than horizontally to minimize the effects of neglect: total errors: 11.48; number of perseverative: 4.11). He scored in the normal range on the Similarities and Comprehension subtests of the Wechsler Adult Intelligence Scale (Revised), with age-scaled percentiles of 38 and 75, respectively. His Digit Span was also normal (90 percentile). He was markedly impaired on Object Assembly and Block Design, however (<1 and 10 percentile, respectively). His estimated premorbid IQ was 110 (National Adult Reading Test) and he was not significantly depressed nor anxious (Hospital Anxiety and Depression Scale: 4 and 0 for depression and anxiety respectively). He was fully oriented for time, place and person.

The first three experiments were conducted during the period 11-12 weeks post stroke. Experiment 4 was conducted 2 weeks after the subject suffered an extension to his stroke on 29 April 1991.

EXPERIMENT 1

Aim

To compare the effects of left hand movements (within the affected hemifield) vs normal performance and visual-cueing instruction respectively, on a test of letter cancellation.

Method

The letter cancellation subtest of the Behavioural Inattention Test was used [18] under three conditions (10 administrations of each condition, with three conditions randomized across the 30 administrations).

The first condition was the standard administration of the test. Condition 2 was administration of the test in conjunction with the motor activity. This involved the subject laying his left arm palm upwards on the table 10 cm from the left margin of the cancellation test and moving the fingers of this hand for 1 sec whenever the experimenter signalled.

The signal consisted of a single knock on the desk, accompanied by the instruction "Now.". The interval between signals was a mean of 8.0 sec (SD 2.4). He was also instructed to look at his fingers moving whenever he moved them.

The third condition required the subject to place his arm in an identical position to the left of the test. However now, he was instructed to "blind" his left arm at the beginning of each single administration of the letter cancellation test, with no further instructions being given during it (i.e. the "visuo-perceptual anchoring" condition). Conditions two and three are not directly comparable because monitoring of eye movements was not possible and hence no attempt was made to equate the motor responses with the eye movements. (This failing is remedied in experiment 3 below).

Results

Figure 1 shows the results. A repeated measures analysis of variance across the three conditions revealed a significant main effect for condition ($F=17.0$; $P<0.0001$). Scheffe F -tests on the inter-condition comparison revealed a significant difference ($F=16.4$; $P<0.05$) between the normal condition (mean error=18.2; SD=5.1) and the hand movement condition (mean error=6.3; SD=4.5). There was also a significant difference (Scheffe $F=7.4$; $P<0.05$) between the hand movement condition and the perceptual anchoring condition (mean error=14.3; SD=3.4). There was no significant difference between the normal and perceptual anchoring conditions.

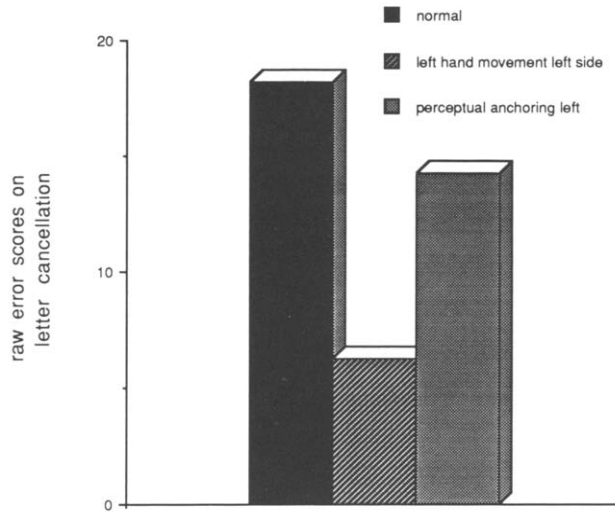


Fig. 1. Letter cancellation: normal vs left hand movement left side vs left visual-perceptual anchoring instruction.

Discussion

In this experiment, contralesional finger movements significantly reduced the degree of neglect shown, in comparison with both the normal and perceptual anchoring conditions, with there being no differences between the latter two.

This suggests that the motor response is more potent than a visual cueing instruction, though of course the motor response may simply serve to be a more salient perceptual cue, whether visual or spatial.

It is however important to note that there was no way of actually controlling for the degree of perceptual anchoring actually demonstrated by the patient. This is dealt with in experiment 3 below.

In order to explore the effects of motor activation more thoroughly, experiment 2 was carried out.

EXPERIMENT 2

Rationale and aims

In order to determine whether the effects of contralesional hand activation were mediated by increased visual scanning, this experiment examined the effects of hand movements on neglect where the hand was masked and could not be viewed by the subject. If visual scanning is the crucial factor, then neglect should be unaffected by hand movements which cannot be seen.

It was not possible in experiment 1 to adequately test the hypothesis that the crucial element of motor activation is the limb moved, as opposed to the hemisphere in which the movement takes place. Hence a second aim of this experiment is to compare the effects of "blind" left hand movements in left hemisphere with "blind" left hand movements in right hemisphere.

Inclusion of a right hemisphere motor activation condition also allows one to test for the

possibility that the motor activation condition is mediated by an increased general arousal induced by the task demand, and that this results in a reduction in neglect for reasons unrelated to the side of the activity. FLEET and HELLMAN [2] have proposed such a mechanism as a possibility.

Method

The letter cancellation subtest of the Behavioural Inattention Test was again used, and again there were three conditions (10 administrations of each condition, with three conditions randomized across the 30 administrations).

As in the previous experiment, the first condition was the standard administration of the test. Condition 2 was administration of the test in conjunction with the identical motor activity to condition 2 in the previous experiment, with the major difference that the subject's hand was concealed behind a board 40 cm broad by 30 cm high. As before, the subject laid his left arm on the table 10 cm to the left of the test and moving the fingers of this hand whenever the experimenter signalled.

The third condition required the subject to cross his left hand to his right knee under the table (it was not possible to have him permanently lay his left hand on the right side as it obstructed his performance on the test). His left hand was now in right hemisphere, and was invisible below the table. He was required to move his fingers whenever the experimenter signalled.

The mean time between left hand movements on the left side was 6.2 (SD 1.1) and on the right side 6.3 (SD 1.3), a non-significant difference ($t = -0.15$; ns).

The left hand should ideally have been in equivalent positions in left and right hemisphere respectively during this experiment, whereas in fact it was on the desk in left hemisphere and on the subject's knee in right hemisphere.

Placing the left hand to the right of the test on the desk would have been physically impossible for the subject, however, and in order to ensure comparability with the condition 2 of experiment 1, it was necessary to keep the left hand on the desk and not change it to the knee position.

Results

Figure 2 shows the results. A repeated measures analysis of variance across the three conditions revealed a significant main effect for condition ($F = 22.3$; $P < 0.0001$). Scheffe F -tests on the inter-condition comparison revealed a significant difference ($F = 19.4$; $P < 0.05$) between the normal condition (mean error = 14.0; SD = 4.6) and the blind left hand/left side movement condition (mean error = 4.3; SD = 1.7).

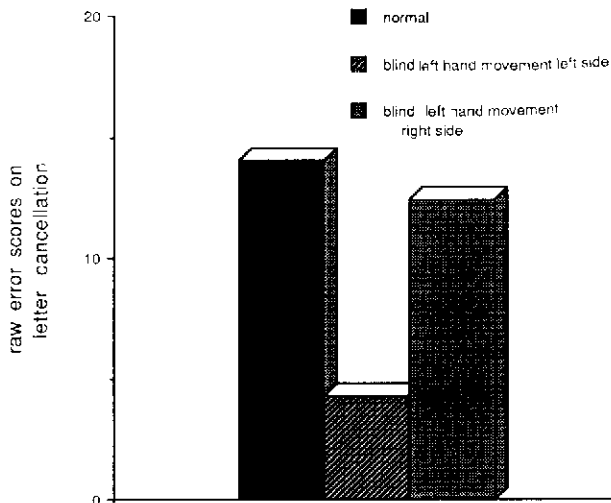


Fig. 2. Letter cancellation: normal vs blind left hand movement left side vs blind left hand movement right side.

There was also a significant difference (Scheffe $F=13.6$; $P<0.05$) between the left side movement condition and the right side movement condition (mean error = 12.4; SD = 3.3). There was no significant difference between the normal and right movement conditions.

Discussion

The visual cueing aspect of the motor activity appears to be irrelevant, according to the results of this experiment. Scrutiny of Figs 1 and 2 shows that reductions in neglect with left hand activation were as great when the hand was visible to the patient as when it was invisible. But activation of the left hand in right hemisphere had no effects on neglect.

This further supports the conclusions of the previous experiment which suggested that the motor activation aspect of the treatment is particularly important. Motor activation does not appear to affect neglect through the visual stimulation associated with it, though of course the spatio-motor (in the terms of Halligan and Marshall outlined in the Introduction above) cueing may indeed attract more attention to left hemisphere irrespective of any visual process.

This experiment also fails to support the notion that any movements by the contralesional limb will reduce neglect: the left hand moving equally frequently in right hemisphere had no effects on neglect. This finding is in line with the conclusions of HALLIGAN *et al.* [5] for line bisection. This of course also rules out the general arousal explanation.

However, the role of visual cueing—i.e. “visuo-perceptual anchoring”—as one possible mechanism cannot yet be completely ruled out. This is because it was not possible in the perceptual anchoring condition of experiment 1 above to monitor whether the subject actually did make frequent eye movements to bring his left arm into his intact visual field, resulting in a spurious negative result (at least as far as visual perceptual anchoring is concerned). The third experiment tests this hypothesis.

EXPERIMENT 3

Rationale and aims

The main aim of this experiment is to determine whether a visually-based perceptually anchoring instruction (where actual scanning can be monitored) can produce reductions in neglect similar to those produced by “blind” hand movements in the neglected hemifield.

A subsidiary aim is to replicate the results of experiment 2 above, which found that “blind” left hand movements in left hemisphere produced significant reductions in neglect on letter cancellation.

Method

The letter cancellation subtest of the Behavioural Inattention Test was again used, and again there were three conditions (10 administrations of each condition, with three conditions randomized across the 30 administrations).

As in the previous experiments, the first condition was the standard administration of the test. Condition 2 was identical to condition in the previous experiment, i.e. hand movements made behind a board on the subject's left side.

Condition 3 was a visually-based perceptual cueing condition where responses could be monitored. This was done simply by placing a clock 10 cm to the left of the test sheet. The subject was instructed to read the number on the seconds dial of the clock each time the experimenter signalled.

The mean time per response in the “clock” condition was 9.6 (SD 5.2) and in the hand movement condition 9.0 (SD 4.8), a non-significant difference.

RESULTS

Figure 3 shows the results. A repeated measures analysis of variance across the three conditions revealed a significant main effect for condition ($F=41.9$; $P<0.0001$). Scheffe F -tests on the inter-condition comparison revealed a significant difference ($F=34.8$; $P<0.05$) between the normal condition (mean error=12.7; $SD=4.1$) and the hand movement condition (mean error=2.6; $SD=1.4$). There was also a significant difference (Scheffe $F=27.6$; $P<0.05$) between the hand movement condition and the perceptual anchoring condition (mean error=11.6; $SD=2.9$). There was no significant difference between the normal and perceptual anchoring conditions.

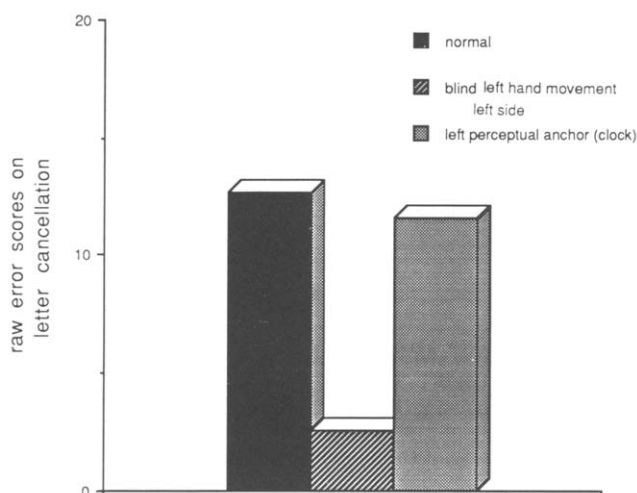


Fig. 3. Letter cancellation: normal vs blind left hand movement left side vs visual perceptual anchoring left (clock).

Discussion

The main hypothesis of this experiment was supported; visual cueing failed significantly to reduce neglect, even though it occurred with the same frequency as the (invisible to the subject) hand movements. Hand movements did however apparently reduce neglect, as was the case in the previous experiment.

This supports the hypothesis that the motor response is a particularly important aspect of the phenomenon, in comparison with a purely perceptual cueing factor, though, as was mentioned above, the motor response may still serve to affect visual scanning through non-visual spatio-motor cueing.

EXPERIMENT 4

Rationale and aims

The apparently privileged role of moving the left hand in left hemispace in reducing neglect, suggested by the previous experiments, fails to support a version of the recruitment hypothesis proposing that contralesional limb movement activates attentional motor

circuits which reduce neglect: left hand movements in right hemisphere had little effect on errors. On the face of it, this would support the cueing hypothesis against the recruitment hypothesis.

One could discriminate between these two hypotheses, however, by examining the effects of *right* hand movements in left hemisphere: according to the cueing hypothesis, these should lead to a reduction in neglect. A failure to find such an effect would, on the face of it, leave both major hypotheses unsupported by the evidence.

Additional clinical information

Between experiments 3 and 4, the subject suffered an extension to his stroke (29 April 1991) which reduced his ability to make hand movements to a very weak pincer grasp between his left forefinger and thumb. A CT scan carried out on 4 June 1991 confirmed extension of the stroke to the right anterior cerebral artery territory superiorly. This scan showed no change in the parietal lesion compared to the February 1991 CT scan, and the left hemisphere continued to be free of any signs of damage.

Method

The experimental method had to be changed in this experiment for two reasons. Firstly, it required finger movements in left hemisphere, making it impossible to use a motorically based cancellation test because of the impaired left hand. Secondly, the capacity for motor movement had by now sufficiently reduced (because of the stroke extension) that the type of finger movement used in the previous three experiments was no longer possible.

The test used in experiment 4 was a sheet of paper identical in size (A4) to the cancellation test, consisting of 40 numbers and letters randomly spread across the sheet. The task for the subject was simply to read all the numbers and letters he could see.

The motor activation procedure had to be carried out with his left hand on his left knee, with his right hand in the same position for that condition. The response required was pressing a very sensitive switch held between thumb and forefinger. The switch was 1.5 cm thickness, 5 cm tall and 4 cm wide. It lay in his upturned hand, with the pressure-sensitive switch resting in the palm and was activated by very slight pressure exerted by thumb and forefinger. Both hand and switch were out of his line of vision under the table.

The switch was attached by cable to a "Neglect Alert Device".* This consists of a small metal box, roughly 12 cm by 8 cm by 2 cm. The device can be set such that it emits a buzzing noise if the switch is not pressed within a predetermined, and variable, time interval. The box was placed 10 cm to the left of the test paper on the desk.

The cue to make the motor response in this case was the buzzing sound emitted by the Neglect Alert Device. The interval between buzzes was varied by the experimenter and was a mean of 8.3 (SD 2.1) sec in the left hand response condition and 7.9 sec (SD 1.8) in the right hand response condition. This difference was not significant.

The reading test was given, as before, under three experimental conditions (10 in each condition), with the trials randomly assigned to the three conditions.

The first condition was again the standard administration of the test. Condition 2 was administration of the test with blind left hand responses in left hemisphere, and condition 3 was the reading test while making blind right hand responses in left hemisphere.

Results

Figure 4 shows the results. A repeated measures analysis of variance across the three conditions revealed a significant main effect for condition ($F = 3.88$; $P < 0.04$). Scheffe F -tests on the inter-condition comparison revealed a significant difference ($F = 16.4$; $P < 0.05$) between the normal condition (mean error = 18.1; SD = 4.0) and the left hand movement condition (mean error = 12.8; SD = 3.4). The mean error in the right hand/left hemisphere condition was 16.3 (SD 5.9), but there were no other significant differences between conditions.

Discussion

In this experiment, minimal left finger movements significantly reduced the degree of neglect shown, in comparison with the normal condition, but not in comparison with the

*Technical specifications of the Neglect Alert Device are available from C. Geggie, Bioengineering Unit, Princess Margaret Rose Hospital, Fairmilehead, Edinburgh, Scotland.

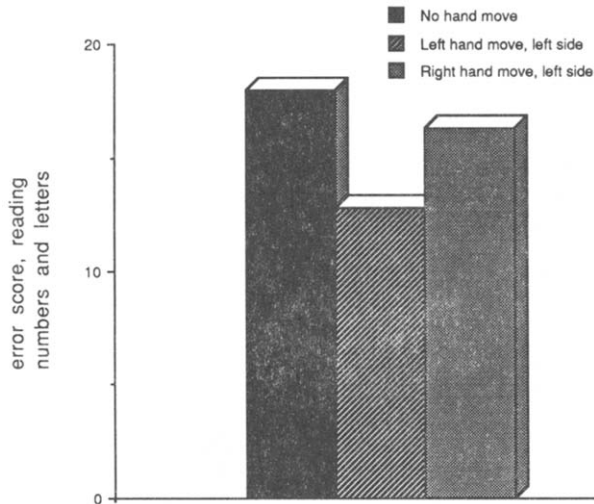


Fig. 4. Letter and number reading: normal vs right hand left side movement vs left hand left side movements.

right hand/left hemisphere condition. The latter did not differ significantly from the normal condition.

This suggests that the cueing hypothesis is inadequate to account for the data in this case: a pre-requisite for the phenomenon in question appears to be a *combination* of left motor responses in left hemisphere: neither right hand responses in left hemisphere nor left hand responses in right hemisphere produced the phenomenon.

GENERAL DISCUSSION AND CONCLUSIONS

Experiment 1 found that left finger movements in left hemisphere reduced neglect compared to a normal condition of letter cancellation and also compared to a general instruction to "find the left arm" prior to each letter cancellation trial.

Experiment 2 compared "blind" finger movements by the left hand in left and right hemisphere respectively with normal cancellation performance. Only finger movements in left hemisphere significantly reduced neglect.

Experiment 3 compared blind finger movements in left hemisphere with a passive visual anchoring procedure in left hemisphere—i.e. reading the second counter on a clock at regular intervals. Only the blind finger movements significantly reduced neglect compared to the other two conditions.

Experiment 4 compared neglect during a reading task with neglect on the task while making minimal finger movements in left hemisphere with the left and right hands, respectively. Only left finger movements in left hemisphere seemed to reduce the neglect.

Returning to the competing "recruitment" and "cueing" hypotheses outlined in the introduction, it would appear from the above four experiments that neither is adequate, at least in its simplest form. Left finger movements may cue attention to the left, but only if performed in left hemisphere. Right finger movements in left hemisphere did not, however, reduce neglect in comparison to normal performance.

Furthermore, if there was indeed a cueing effect, it appeared to operate independently of

the visual system, at least in this case: being able to see the finger movements offered no advantage to this subject. A simple recruitment hypothesis is also inadequate: left hand movements in right hemispace had no effect. Can existing theoretical models of visuo-spatial functioning clarify these findings?

Hemispatial vs hemicorporeal factors

Normal subjects will react faster to a right-sided auditory stimulus with their right hand than with their left, and *vice versa* for left-sided stimuli. That is with their hands in a normal uncrossed position, however. When the arms are crossed across the body midline, left stimuli elicit faster responses by the right hand (located in left hemispace) than by the left (located in right hemispace) (e.g. Ref. [14]). Such stimulus-response compatibility has also been demonstrated in the visual and other modalities (e.g. Refs [9] and [17]).

This finding suggests that under some conditions, side of space is dominant over side of body in mediating responses in space. Such a finding also pertains to brain damaged patients, with HEILMAN and his colleagues (e.g. Ref. [6]), suggesting that some subjects with unilateral neglect suffer from a "hemispatial hypokinesia", namely a difficulty in making responses with *either* limb in the hemispace contralateral to the lesion.

These results suggest that one might modify the recruitment hypothesis considered in the present experiments such that it refers to *hemispatial* activation, rather than to *hemicorporeal* activation. Though the negative results of experiment 4 above apparently also go against such a reinterpreted hypothesis (i.e. "activating" the left side of space by moving the right hand on the left), consideration of a sophisticated theory of spatial behaviour advanced by Rizzolatti and his colleagues may help to elaborate the relationship between hemispatial and hemicorporeal factors.

Rizzolatti's theory of spatial functioning

Rizzolatti and his colleagues suggest that multiple and dissociable spatial frames of reference exist in both humans and animals, and these may be selectively impaired [11, 12].

They [11, 12] have demonstrated in monkeys that space is coded in dissociable ways by different brain centres, and that damage to one centre may result in unilateral neglect for one spatial system but not for another. For instance, they show that frontal eye field neurons use visual information to control purposeful eye movements, while inferior area 6 neurons use somatosensory and peripersonal visual information to organize purposeful somatic movements. Lesions in these different areas produce corresponding different types of spatial deficit. A recent case study demonstrates related dissociations between neglect for peripersonal and locomotor space in man [3].

Rizzolatti proposes the existence of multiple representations of space by these different spatial systems, interacting together to produce a coherent spatial reference system against which purposeful motor movements are calibrated and organized. It is the parallel activity of these different perceptuo-motor neural maps which produces representation of space, and, conversely, it is their breakdown which creates distorted representations.

Applying this theory to the case in the present study, the subject may have been suffering neglect with respect to *at least* two independent but nevertheless integrated spatial systems—a "personal" space related in some way to some somato-sensory representation of his body, and a peripersonal or "reaching" space within which he manifested such deficits as neglecting the left in letter cancellation.

By inducing the subject to make voluntary movements with his left hand in left hemispace,

it is possible that the left half of the somato-sensory spatial sector was in some way activated or enhanced. Because of the integration of the somato-sensory and peripersonal spatial sectors, this in turn produced enhanced activation of the impaired half of peripersonal space. Such is the interpretation which would follow from Rizzolatti's work.

But why did not left hand movements in right hemisphere similarly activate the left side of peripersonal space? After all, though left hemisphere may not have been activated, the left side of the body was being activated. One possibility is that reciprocal activation of more than one corresponding spatial sector of the closely-linked neuronal maps in the brain must be activated to overcome the deficit in representing the left side of space.

In other words, cueing/recruitment of the hemispacial system was inadequate on its own. So also for the hemicorporeal ("personal") system. Only when both were activated simultaneously did some improvement of spatial perception of the left arise, possibly by some kind of reciprocal activation across the related neuronal systems.

Generalizability of the results

According to Rizzolatti's theory, perception and action input and output are intimately integrated, and hence procedures requiring motor responses in left hemisphere should be more effective than visual cueing procedures such as those used in the current experiments. The lack of *any* effect of visual cueing in the present study is however not readily deducible from Rizzolatti's theory: his model allows for activation of spatial sectors via visual cueing [11] as well as other types of activation.

One hypothesis to account for the lack of visual cueing effects is to argue that the patient in question had a primarily "output" or "premotor" neglect, as opposed to an "input" or "perceptual" neglect.

TEGNER and LEVANDER [15], COSLETT *et al.* [1] and others have suggested the existence of these two types of neglect. The former is compatible with HELLMAN *et al.*'s [6] notion of "hemispacial hypokinesia" and reflects an impairment of the ability to make motor movements with either limb in contralesional hemisphere. There is some suggestion that this may be associated with anterior lesions. "Sensory" neglect, on the other hand, is reflected in an impairment in the ability to orient to stimuli in contralesional hemisphere. Most neglect patients appear to suffer from both types of disorder [16], however.

If the present case does have a primarily "premotor" neglect, then the reason that left hand activation was effective when visuo-perceptual cueing was not could be explained by saying that he had little difficulty in attending to stimuli on the left: rather, his problem was in making motor (and perhaps oculomotor) responses to the left side of space. Such a deficit might require "motor cueing" of the type used in the present experiments, while another subject with a primarily input type of neglect might benefit from visual cueing and not from motor cueing. This hypothesis must await demonstration of the existence of such a case.

The precise theoretical underpinning of the present results must await further research. Neither cueing nor recruitment hypotheses can be eliminated and it is likely that both types of mechanism must be invoked to explain the data.

The rehabilitation implications of the types of spatio-motor activation procedures used in the present study have however been explored in three single case studies by the present authors [13] which showed clinically significant improvements in both test and everyday life functioning of three patients treated by a left limb activation procedure.

Acknowledgements Many thanks to the subject of this study for his generous and patient participation in the

research. We would also like to thank the staff of the Astley Ainslie Hospital, for their help and support in carrying out this study as well as Susan Goodrich in Cambridge for her painstaking comments on an earlier draft of this paper.

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