Left hand movements and right hemisphere activation in unilateral spatial neglect: a test of the interhemispheric imbalance hypothesis

Guido Gainotti a,∗, Roberta Perri b, Antonella Cappa a

a Neuropsychology Service, Università Cattolica/Policlinico Gemelli, Largo A. Gemelli, 8 00168, Rome, Italy
b IRCCS Clinica Santa Lucia, Rome, Italy

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Abstract

The aim of the present study was to check one of the main assumptions of the interhemispheric imbalance hypothesis, namely, the prediction that the severity of neglect should be reduced by conditions activating the right hemisphere. To achieve this, a group of neglect patients was studied using a slightly modified version of the limb activation technique. The (verbal or visuo-spatial) nature of the stimuli to be processed by the patient and the (left or right) side of space where the left hand moved were considered as the critical variables to check the interhemispheric imbalance hypothesis.

Three traditional and one new methods were used to measure changes induced in the severity of neglect by the material to be processed or by the side of space where the left hand moved. The traditional methods, all based on counting omissions, consisted of measuring: (a) the overall number of omissions; (b) the number of omissions made on the left half sheet; or (c) the difference between the omissions made on the left and right sides of the sheet. The new index, based on the notion of the ‘attentional field’ and defined as the spatial distribution of stimuli detected by the patient, was operationally measured by computing the distance between each stimulus crossed out by the patient and the right margin of the sheet. The study was conducted by rating the severity of neglect in 42 cancellation sheets which had used, respectively letters (N = 21) and small geometric figures (N = 21) as targets. The two sets of cancellation sheets were obtained from seven neglect patients during a limb activation task requiring the cancellation of a given target in three different conditions: (a) baseline; (b) active movements of the left hand in the left half space; (c) active movements of the left hand in the right half space.

Results were at variance with the predictions based on Kinsbourne’s model, since the verbal or visual spatial nature of the material to be processed did not influence the severity of unilateral spatial neglect (USN) and since left hand movements produced a significant reduction in the severity of neglect only when these movements were made on the left side of space. © 2002 Elsevier Science Ltd. All rights reserved.

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1. Introduction

Unilateral spatial neglect (USN) can be considered the most frequent and dramatic behavioral defect of patients with right hemisphere damage [8,10] and as a major factor in poor recovery after stroke [7]. Therefore, several authors have tried to develop rehabilitation techniques or to search for experimental conditions that can temporarily or persistently reduce hemineglect. The best known and most effective experimental condition which can transiently reduce USN is caloric vestibular stimulation, proposed by Rubens [37] and developed by Cappa et al. [4], Vallar et al. [39,41], and Rode et al. [36]. Rubens reasoned that if unilateral neglect is partly due to a gaze and postural turning bias, then caloric vestibular stimulation, producing eye deviation and past-pointing in the direction opposite to this bias, should reduce the tendency to neglect stimuli in the contralateral half space. His results strongly supported the hypothesis since, even in patients with severe neglect, vestibular stimulation markedly improved performance on tests of visual neglect. Effects similar to those observed after caloric vestibular stimulation have since been obtained using other techniques such as optokinetic stimulation [29,38], trunk midline orientation [23], neck muscle vibration [21,23] and transcutaneous electrical nervous stimulation [22,40].

However, the interpretation of these well-established findings remains controversial. Some authors maintain that the structures recruited during caloric vestibular stimulation and other facilitatory techniques contribute to the generation of a body centered spatial map for directing attention and movements toward extrapersonal space. According to this interpretation, USN should be considered as an orienting bias produced by defects in a central reference system.
and all the above mentioned techniques could contribute to restoring this spatial map, thus reducing the imbalance in the system [23,29,38]. An alternative interpretation, more in line with the ‘peripheral’ hypothesis that prompted Rubens’ seminal experiment, assumes that all these manoeuvres act on the output systems of this integrated reference frame, thus reducing the consequences of its imbalance. For example, by provoking a forced automatic gaze displacement, caloric vestibular stimulation and optokinetic stimulation could prompt a correlative automatic displacement of attention, since direction of eye movements and direction of attention are closely related in spontaneous and uncontrolled conditions [18]. Similar reasoning could be applied to other techniques which influence the severity of neglect by manipulating other components of the spatial orienting apparatus (see [10,11] for a more thorough discussion of this issue).

An important contribution to clarifying this issue could come from the study of other facilitatory techniques based on the activation of body parts, such as the limbs, which should be less critically involved in the construction of the body reference frame. However, it must be noted that even if several authors have shown through the use of different experimental paradigms that active movements of the left hand can improve the severity of USN, the mechanism underlying this improvement is still controversial.

Joanette and coworkers [19,20] and Robertson and coworkers [32–35] attributed the improvement of neglect observed after left hand movements to the activation of the right hemisphere premotor systems associated with the use of the left hand. This interpretation, which is based on ‘premotor’ model of neglect of Rizzolatti and coworkers [30,31], assumes that since attentional and motor circuits are intimately linked in the brain, the activation of the right hemisphere motor circuits should lead to a recruitment of the associated attentional mechanisms, thus improving attention to the left side of space. On the other hand, Halligan and coworkers [14,16] showed that the left hand advantage for line bisection performance is reduced when this hand starts from the right extremity of the line. These authors proposed that the left hand acts as a cue enhancing attention to the left side of space. Still other authors (e.g. [25,27]) proposed that by increasing the activity of the right hemisphere, left hand movements may counteract the interhemispheric imbalance which, according to Kinsbourne [24,25], subserves the clinical manifestations of neglect. In fact, Kinsbourne’s influential model assumes: (a) that attention may be directed along a vector resulting from the interaction of paired opponents processors controlled, respectively by the right and left hemisphere and (b) that neglect resulting from right hemisphere damage may be modified by reducing (or increasing) the interhemispheric imbalance via activation of the right (or respectively of the left) hemisphere.

The aim of the present research was to try to check this last hypothesis by means of a slightly modified version of the ‘limb activation technique’ proposed by Robertson and North [32–34]. In their basic experiment, conducted on patient TD, these authors showed that a reduction of left-sided neglect can be observed when the patient voluntarily moves the fingers of his left hand in the left half space. This effect, evaluated by using the total number of omissions made on the letter cancellation sub-test of the Behavioural Inattention Test [42] as a measure of neglect, was not dependent on the patient’s limb being in view, was not obtained when the left hand moved in the right half space and was not produced by a passive movement of the same hand. Robertson and North’s study was criticized on methodological grounds by Cubelli et al. [6], and only in part confirmed by Ladavas and coworkers [9,26]. Cubelli et al. [6] argued that, since patients with USN usually also have a generalized attentional impairment in addition to a lateralized defect of space exploration, it is possible that left hand movements, by improving the level of arousal, may reduce the total number of omissions without reducing the right–left asymmetry that is the hallmark of USN. Ladavas and coworkers [9,26], on the other hand, showed that the severity of neglect can be reduced not only by active, but also by passive movements of the left hand. In spite of these minor objections, several studies confirmed that active movements of the left hand can reduce the severity of neglect [2,5] or of visual extinction [28].

In our study, we intended to replicate this experiment in an unselected group of neglect patients by keeping under control two variables which (according to the ‘interhemispheric imbalance hypothesis’) should influence the severity of neglect in a predictable way. These variables are the following: the (right or left) half space where the left hand moves and the (verbal or visual–spatial) nature of the material used to measure the severity of neglect. We predicted that if left hand movements reduce the severity of neglect by activating the right hemisphere, then: (a) these movements should improve the severity of USN, irrespectively of the half space where the left hand moves since, in any case, the left hand movements should activate the right hemisphere; (b) neglect should be more severe with visual–spatial stimuli, which activate the right hemisphere, than with verbal stimuli, which activate the left hemisphere. This last prediction had been previously checked with conflicting results by other authors [3,5,17], but perhaps these contrasting results could be explained by methodological considerations. One of these could be the measures used to evaluate the severity of neglect since, according to Kinsbourne [24,25], in USN the attentional defect is not limited to the left half space, but shifts along a continuum from the extreme right to the extreme left half space. Now, since the standard measures used to evaluate the severity of neglect on a cancellation task are substantially based on the number of omissions made on the right and left half sheet, they are probably inappropriate for testing the interhemispheric imbalance hypothesis and it was necessary to find a more appropriate measure of neglect to test this dynamic model.
Therefore, in our study we used a new method, labeled the center of the ‘attentional field’, devised to evaluate the spatial distribution of the patient’s attention, in keeping with Kinsbourne’s construct of neglect, in addition to three traditional measures of the severity of neglect. The latter were based on the total number of omissions made on the cancellation sheet, the number of omissions made on the left half sheet and on the difference between the omissions made on the right and left half sheet.

2. Patients and methods

2.1. Patients

Data used to check our working hypothesis were gathered on seven right brain-damaged patients with clinical evidence of left neglect, but spared ability to move the left hand, at least in part.

These patients were selected from a consecutive series of patients who had been referred to the Policlinico Gemelli in Rome over a 2-year-period (from June 1997 to June 1999) due to a recent stroke. The main selection criteria were the following: (a) a single right hemisphere lesion due to a recent stroke, as documented by clinical and neuroimaging data; (b) the presence of left visuo-spatial neglect in at least three out of the following four standard tests of neglect: (i) line cancellation [1], (ii) line bisection [15], (iii) identification of overlapping figures [12], (iv) copy of a composite figure [13]; (c) a spared ability to move at least in part the forefingers of the left hand.

Patients’ ages ranged from 67 to 78 years, educational level from 4 to 17 years of schooling and duration of illness from 1 week to 3 months. Neglect was mild in two patients, moderate in three and severe in the last two patients. The left hand motor defect was moderate in three patients, mild in two and absent in the last two patients.

2.2. Experimental procedure used to study the effects of limb activation

The method used to check the influence of the active movements of the left limb on the severity of neglect was very similar to that of experiment 2 by Robertson and North [34]. Two A4 sheets of paper, each containing 420 small stimuli (upper case letters on sheets 1 and small geometric figures on sheet 2) scattered across the sheets, were presented to the patients. On sheet 1, the 420 stimuli corresponded to seven geometric figures, each of which was repeated 60 times, i.e. 15 times for each quadrant of the sheet. On sheet 2, the stimuli corresponded to seven geometric figures, each of which was again repeated 60 times (15 for each quadrant of the sheet). The patient was requested to cancel each example of a given stimulus (an upper case letter on sheet 1 and a small geometric figure on sheet 2) under three different conditions. The first condition was a standard cancellation test. The second was a cancellation task made in conjunction with an active movement of the left hand in the left half space (the left hand was lying on the patient’s left knee, invisible below the table). The third condition was again a cancellation task in conjunction with an active movement of the left hand; but this time the patient’s hand was crossed on his right knee and was, therefore, placed in the right half space. In both conditions 2 and 3, the order to move the left hand fingers was given to the patient every 10 s and in each case, the patient had to move the fingers for 1 s.

2.3. Parameters used to evaluate the effects of the left hand movements on the severity of visual neglect

For each patient, six cancellation sheets (two kinds of stimuli × three conditions) were available to evaluate the influence of the left hand movements on the two sides of space and the influence of the stimulus material on the severity of neglect. For each sheet, the following parameters were computed: (a) total number of omissions of the target stimulus made on the whole sheet; (b) total number of omissions made on the left half sheet; (c) difference between the number of omissions made on the left and right half sheet; (d) central point of the patient’s ‘attentional field’. This last parameter was operationally defined as the portion of the sheet taken into account by the patient during the cancellation task. Its central point was computed by measuring the distance of the center of each stimulus cancelled by the patient from the right margin of the sheet and considering the mean value of these measures as the center of the attentional field.

3. Results

3.1. The influence movements of the left hand on the right and left sides of space can have on severity of neglect

Due to the small size of our experimental sample, the influence movements of the left hand on the right and left sides of space can have on the severity of neglect was studied by pooling together results obtained with verbal and visual–spatial stimuli. Data necessary for this analysis were obtained by computing four kinds of measures (namely, total number of omissions, left-sided omissions, left minus right-sided omissions and center of attentional field) for each patient in three experimental conditions: (1) baseline; (2) left hand movements on the left side of space; (3) left hand movements on the right side of space.

The number of observations was 14 (a ‘verbal’ and a ‘visual–spatial’ cancellation sheet × seven neglect patients) for each experimental condition. Paired ‘t’-tests were used to check the significance of differences observed between the baseline and the two
The Center of the attentional field 11.63 left-sided 17.6 left-sided omissions relationships between the verbal or visual–spatial nature of the stimuli and results obtained on cancellation tasks Table 2 activation' hypothesis. This finding is clearly at variance with the 'right hemisphere left, but minimally to the right with visual–spatial stimuli. moving along a right-to-left gradient, is not shifted to the center of the attentional field, hemisphere). In particular, the center of the attentional field, right hemisphere) than with geometric figures (activating the right hemisphere). This approach to the problem, neglect should be more severe on the letter cancellation than on the geometric figures cancellation task. Regarding the first variable, it was reasoned that since verbal stimuli should mainly activate the left hemisphere, whereas visual–spatial stimuli should lead to a prevalent activation of the right hemisphere, neglect should be more severe on the letter cancellation than on the geometric figures cancellation task. Regarding the second variable, it was argued that if left hand movements improve the severity of neglect by activating the right hemisphere [24,25,27], then the space where the left hand moves should have only a marginal influence on this improvement, since in any case left hand movements improve the severity of neglect only when the left hand moves in the left side space. However, results obtained following the first line of research were rather controversial. Data reported by Hellman and Watson [17] supported Kinsbourne’s hypothesis, whereas data reported by Caplan [3] and Cermak et al. [5] did not support this model. Furthermore, the data reported by Robertson and North [34] obtained on a single experimental conditions. Results of this analysis are reported in Table 1. In three out of the four measures of severity of neglect (namely, overall number of omissions, left-sided omissions and center of the attentional field), left hand movements in the left half space produced a significant reduction in the severity of neglect. On the contrary, left hand movements in the right half space did not significantly influence severity of neglect in any of these measures.

3.2. Relationships between results obtained with verbal and with visual–spatial stimuli

Table 2 reports the severity of neglect, evaluated with the four different measures mentioned in the previous sections, based on number of omissions and on center of the ‘attentional field’, as a function of the verbal or visual–spatial nature of the stimuli to be cancelled. The number of observations was 21 for each kind of stimuli, corresponding to the seven patients x the three experimental conditions.

The results reported in Table 2 show that the (verbal or visual–spatial) nature of the stimuli used to assess the severity of neglect; (2) the side of space where the left hand moved. Regarding the first variable, it was reasoned that since verbal stimuli should mainly activate the left hemisphere, whereas visual–spatial stimuli should lead to a prevalent activation of the right hemisphere, neglect should be more severe on the letter cancellation than on the geometric figures cancellation task. Regarding the second variable, it was argued that if left hand movements improve the severity of neglect by activating the right hemisphere [24,25,27], then the space where the left hand moves should have only a marginal influence on this improvement, since in any case left hand movements activate the right hemisphere. This approach to the problem is not quite new. On one hand, other authors [3,5,17] have already tried to check the influence of the nature of the material to be processed on the severity of USN. On the other hand, Robertson and North [34] claimed that neglect improves only when the left hand moves in the left side space. However, results obtained following the first line of research were rather controversial. Data reported by Hellman and Watson [17] supported Kinsbourne’s hypothesis, whereas data reported by Caplan [3] and Cermak et al. [5] did not support this model. Furthermore, the data reported by Robertson and North [34] obtained on a single
It must be acknowledged, however, that both the premotor and the spatio-motor cueing interpretation are at variance with results obtained by Ladavas et al. [26] in their above mentioned paper, which seemed to show that the premotor and the cueing explanation are not tenable. Therefore, we believe that even if the value of a theoretical model cannot be assessed on the basis of a single study, but requires the critical evaluation of several, even contrasting studies, the controversy over the mechanisms by which left hand movements produce a transient reduction of visual neglect cannot be solved with our present knowledge.

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