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Passive limb movements improve visual neglect

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Abstract

Recent studies have reported that left neglect can be ameliorated during *active* movements of a contralesional limb in the contralesional space. In contrast, a *passive* left hand movement does not seem to induce an amelioration of neglect, at least when it is associated to simultaneous *active* right movement (Robertson IH, North N, Neuropsychologia 31 (1993) 293–300). In the present study, we explored the possibility that a *complex passive* movement, such as abduction and adduction of the arm, is able to reduce neglect also when it is associated to simultaneous *active* right arm movements. To test this hypothesis neglect patients were required to perform an object cancellation test and a line bisection test by using the right hand, while the left arm was passively moved. Moreover, we verified the possibility that left arm stimulation activates the peripersonal more than the extrapersonal space, with the exception of the condition in which the far space can be reached by a tool that extends peripersonal space in the far space (Farnè A, Làdavas E, Neuroreport 11 (2000) 1645–1649). For this reason, patients were required to perform the tasks in near (70 cm) and in far (140 cm) space by means of a light pen (pointing task) and of a stick (reaching task).

When the left arm was passively moved the results showed a significant reduction of neglect with respect to the baseline condition, and the improvement equally affected the near and the far space. A different effect for the near and far space was observed in relation to the task (pointing vs. reaching). In the pointing task, neglect was more severe in the far than in near space; however, this difference disappeared when the patients had to reach objects by means of a stick.

In conclusion, the present study shows that the entity of improvement of visual neglect due to a left passive movement is related to the entity of proprioceptive signals specifying left hand position.

Keywords: Amelioration of neglect; Passive proprioceptive stimulation; Cross-modal interaction; Near and far space; Space representation

1. Introduction

Unilateral visual neglect typically produces inattention for stimuli located on the left (or contralesional) side of space. The deficit has been conceived as a representational deficit due to the competition between left and right space representations [4,9,10,21,34].

The unilateral damage of a brain area with a contralateral field representation results in a reduction of competitive weights in the affected field. After a right brain damage, the activation of a contralateral space representation is weak and, as a consequence, the competition with intact ipsilesional space representation induces neglect in that sector of space. The competition might operate on a number of different topographically mapped brain areas encoding both the input and output components of responses, each of them contributing to the construction of the perceived space representation. The antagonism between left and right space representation, however, may be reduced by the activation of a spatial representation mapped in another right brain structure, which co-operates, through mutual excitation, with the damaged representation. The reduction of this antagonism will produce a better level of activation of the left-side representation of the space and, as a consequence, it will increase the level of detection for left-sided stimuli.

For example, it has been shown that the level of awareness of left-sided stimuli presented in the extrapersonal space can be increased by rendering the proprioceptive signals specifying the position of the left hand more salient [16,21,26]. Halligan et al. [16] showed that

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neglect in a line-bisection test was less severe when the left hand was used, although the effect disappeared when the subject was required to begin the task with his/her left hand positioned in the right space. Therefore, it seems that the spatial position of the hand, more than the responding hand, can be the crucial factor in determining the modulation of neglect. This conclusion has been confirmed by Robertson and North [26]. When patients with neglect were asked to make minimal *finger* movements in the left hemispace with either hand, a reduction of neglect was found *only* in the condition in which the left hand was making movements in the left hemispace. This means that, in order to obtain a reduction of neglect, the hand (left) and the spatial position of the hand (left) have to be combined: neither right hand responses in the left hemispace nor left hand responses in the right hemispace produced an amelioration of neglect.

These studies clearly show that the activation of proprioceptive information related to the position of the limb can modulate the impaired representation related to extrapersonal space. Moreover, it has been shown by Robertson and North [28] that only an active movement of the left hand is able to produce an amelioration of visual neglect, whereas a *passive* left hand movement in the left hemispace does not seem to reduce neglect. A possible explanation for this result is that in their study the patient had to cancel the letters 'E' and 'R', randomly distributed among five rows of letters, by using the right hand; this might have cancelled a weaker effect due to the passive left hand movement. In this case, the left-side representation, evoked by a passive movement, is weaker comparing to the right spatial representation evoked by an active right hand movement.

This interpretation has been confirmed by a study of Làdavas et al. [21] in which patients did not use the right hand to perform the task. In an experimental condition in which patients were required to name objects depicted on a sheet of paper, they found an amelioration of neglect by simply using a passive left hand movement.

A further explanation for the lack of a neglect improvement in Robertson et al.'s study is that a *passive finger* movement might be too weak to compete with an *active* right hand movement. Thus, it is possible to hypothesise that more complex *passive* movements, such as abduction and adduction of the arm, might activate strongly the left side of space producing a reduction of neglect. In this condition, *passive* movements might produce amelioration also when a simultaneous *active* right arm movement is performed in the right space.

In the present study the effect of a left-side passive activation was measured in a condition in which there was not a competing right-side activation (object naming task and perceptual line bisection task) and in a condition in which there was a simultaneous right-side activation (object cancellation task and motor line bisection task). If the proprioceptive activation, produced by the passive abduction and adduction of the left arm, is strong enough to compete with the activation produced by the use of the right arm, no difference between the two experimental conditions should emerge. In contrast, if a passive movement can evoke only a weak left-side space representation, a better performance is expected in the condition in which patients perform the task without a competing right-side movement, i.e. in the object naming and in the perceptual line bisection.

There are some evidence showing that neglect can be reduced by increasing the level of arousal [12,31]. Therefore, a speculative explanation of the expected neglect amelioration can rely on a non-specific increase in arousal caused by an arm passive movement. To check for this possibility, patients performed the perceptual tasks (object naming task and perceptual line bisection task) also during passive right limb activation. Naturally, in this experimental condition, patients could not perform motor tasks (cancellation task and line motor bisection task) due to their severe left motor impairment. If the amelioration of neglect is due to a general alertness effect, then the beneficial effect should be present also during right limb activation.

In selecting repeated measure of spatial behaviour sensitive to neglect, we attempted to sample from three theoretically and empirically distinct domains of space representation. It is now clearly established that neglect for personal, peripersonal, and extrapersonal space can be dissociated from each other [15,17,25]. Personal space is usually referred to a body space, peripersonal space is that immediately surrounding the body and reachable by an arm movement and extrapersonal space is that outside a direct manual reaching. In the present study, we also have explored the possibility that the amelioration of neglect induced by the limb activation might be specific for peripersonal space. For this reason, the experimental material was presented at a distance of 70 cm (near space) or at a distance of 140 cm (far space). If left arm stimulation selectively activates the peripersonal space, i.e. the space reachable by the hand, then a better performance is expected, during left limb activation, in the near than in the far space.

Moreover, neurophysiological and neuropsychological findings showed that peripersonal space has important dynamic properties: it can be expanded and contracted depending upon tool use [2,11,19]. Iriki et al. [19] found, in the monkey parietal lobe, bimodal neurons that coded the schema of the hand. These neurons fired when a tactile stimulus was delivered to the monkey's hand and when visual objects were presented near the hand tactile receptive field. The most striking characteristic of these neurons was that their visual receptive field was modified during a reaching movement performed with a rake up to include its entire length and to cover the expanded accessible space. Moreover, the bimodal neurons' visual receptive field was modified only when the monkey reached for an object with a rake and not when the monkey just held the rake.

A single case study by Berti and Frassinetti [2] showed that the use of a stick influenced the computation of far space also in human. They described a patient P.P. who had neglect in near, but not in far space, when she had to bisect a line by means of a light pen. In contrast, when the patient had to reach the line located in the far space by means of the stick, the left part of the line was misperceived, as it was in near space. The reaching to 'far' space with a tool caused an expansion of the impaired near space into the far space. Similar results were found by Farné and Làdavas [11], who investigated this phenomenon in patients with tactile extinction, by using a cross-modal visuo-tactile paradigm well suited to reveal visual peripersonal space near patient's hand. Cross-modal visuo-tactile extinction was assessed far from the hand, at the distal edge of a hand-held rake. They found that cross-modal extinction was more severe after patients used the rake to retrieve distant objects with respect to a condition in which the rake was not used. These results clearly show that the use of a tool increases the spatial extent of the representation of peri-hand visual space to incorporate the tool.

For this reason, patients were required to perform the experimental motor tasks in the near and in the far space by means of a light pen (pointing task) and of a stick (reaching task). In patients with neglect, far space is usually more impaired than near space [6]; however, the use of a stick might reduce the severity of neglect in far space which, due to the stick-use, becomes in effect near space. If this is the case, a better performance is expected for the far space when patients use a stick compared to a light pen. In contrast, patients' performance on the near space should be independent of the use of a light pen or a finger movement response.

2. Subjects and method

2.1. Subjects

Subjects were eight patients with right brain damage and left visual neglect, recruited from 'Don Gnocchi' Hospital in Parma. All had unilateral lesions due to cerebrovascular accidents. Lesion sites were confirmed by CT scans and are reported in Table 1. All patients were right handed. Gender, age and length of illness are reported in Table 1. They were fully oriented in time and place. Motor, somatosensory and visual deficits were assessed through a neurological examination. All patients were affected by left motor impairment, which was more severe in upper than in lower limb. Only one patient was able to use his left upper limb (D.G.). Two patients (R.G. and A.D.) showed a visual field defect. All patients, tested for proprioceptive sensation, had an impairment for the distal joints, with preserved position sense for the proximal joints of the upper left limb.

The presence of visual hemineglect was assessed by using five tests: (1) a line cancellation test [1]; (2) a Bell's cancellation test [13]; (3) a sentence reading test [23]; (4) a line bisection test; (5) a flower drawing test. Patients' performance in each test is presented in Table 2.

2.2. Apparatus

The passive movement was induced by using an instrument for the rehabilitation of motor impairment that passively moves the elbow (Artromod-E). It is composed of a chair and a trolley with a support that firmly holds patient's forearm from below. Patients sat on the chair and grasped with their hand a sphere arranged at the end of the support. According to the experimental conditions, on patients' left (or right) side

Table 1
Summary of clinical data for the patients[a]

Patient	Age (yr)/sex	Time from CVA (months)	Lesion site in right hemisphere
C.A.	58/M	3	F
F.M.	71/F	5	FT
G.D.	62/M	2	Bg; IC; Wm
Z.G.	70/M	3	IC, cerebellum
R.G.	55/M	1	Bg, IC, TPO, Wm
B.N.	71/F	4	FP
A.D.	79/M	10	TPO
D.G.	74/F	30	P

[a] *Note:* F – frontal; O – occipital; P – parietal; T – temporal; IC – internal capsule; Wm – white matter; Bg – basal ganglia; CVA – cerebrovascular accident.

Table 2
Percentage of omissions (line cancellation and Bell's test), percentage of rightward displacement (line bisection), percentage of errors (sentences reading) and correctness of drawing

Patient	Line cancellation (%)		Bell's test (%)		Line bisection (%)	Sentences reading (%)	Drawing of a flower (%)
	Left	Right	Left	Right			
C.A.	60	0	87	80	14	74	+
F.M.	0	0	60	0	7	0	−
G.D.	15	0	100	67	38	85	+
Z.G.	95	35	100	87	38	74	−
R.G.	20	0	47	33	28	44	+
B.N.	5	0	40	13	10	0	+
A.D.	0	0	26	0	12	0	−
D.G.	0	0	60	35	7	18	−

there was the trolley with the support for the forearm and on the other side there was a wheelchair, whereby patients held the right (or left) arm. The trolley was located out of patients' view.

2.3. Material

Two types of material were used to assess neglect in different experimental conditions: drawings of objects and line bisection.

2.3.1. Drawing of objects

On a A4 paper, 30 line drawings of objects from the Snodgrass and Vanderwart [33] set (15 on the left and 15 on the right side) were drawn together with 14 drawings of digits and letters (6 on the right, 6 on the left and 2 on the centre). Seven different versions of the stimulus array were presented one for each experimental session. A transparent copy of a A4 sheet of paper was projected on a white opaque panel (2×2 m^2). Patients sat on the chair in front of it, at a distance of approximately 70 cm (near space) or at a distance of approximately 140 cm (far space). Figures' dimension in the near space was 0.5×0.5 cm^2, in the far space was corrected for the visual angle and it was 1×1 cm^2.

2.3.2. Line bisection

Horizontal lines were drawn in black on A4 sheets of paper, copied onto a transparency and projected on a white opaque panel (2×2 m^2) at a distance of 70 cm (near space) or at a distance of 140 cm (far space). Line length in near space was either 30 cm (short lines) or 78 cm (long lines). Line length in far space was corrected for the visual angle and was either 60 cm (short lines) or 156 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 on the retina.

2.4. Procedure

Patients sat on the chair with their eyes aligned with the vertical and the horizontal midpoints of the projected array. Three different basic conditions were possible: baseline, left stimulation, and right stimulation. In the baseline condition no stimulation was administered. However, in order to control for the possible effect of the noise made by the apparatus, which might act as an auditory spatial cue, the apparatus (Artromod-E) was turned on also in baseline condition, although no stimulation was applied to the patients' limb. In the left stimulation condition, the left forearm was placed on the support of the Artromod-E and the right forearm on the armrest of the wheelchair. Patients' arms were abducted 55° from the patient's trunk, forearms were pronated 90° and bent 90° at the elbow. The left hand was holding a sphere, and the wrist was extended 10°. The left forearm was passively and continuously abducted and adducted of about 15° with respect to the starting position of the movement. The speed at which the arm was moved was 2.5°/s. Limb stimulation began 5 min before the visual task and continued throughout the period in which patients were performing the task. In the left stimulation condition, the left arm movement was executed in the left side of the space. Right stimulation condition was similar to the previous one with the exception that the right arm movement was executed on the right side of the space.

Patients performed each task, objects task and line bisection task, in the following 14 conditions. Each condition was repeated twice: one in which the stimuli were presented in the *near* space and one in the *far* space. Baseline conditions were always run first, and the order was randomised independently for each subject. Patients performed the remaining conditions in a random order.

2.4.1. Object task

(1.1) *Baseline object naming condition*. Patients were required to name all the objects that were projected on the screen while the arms were rested on the legs. Whenever patients named a stimulus, the experimenter marked the stimulus on the transparency; this allowed patients to see which stimuli have been reported.

(1.2) *Left-side stimulation and object naming condition*. This condition was similar to the previous one with the exception that the left patients' arm was passively moved.

(1.3) *Right-side stimulation and object naming condition*. Again, this condition was similar to the baseline condition with the exception that the right patients' arm was passively moved.

(2.1) *Baseline object pointing condition*. Patients were required to point to the objects by means of a projection light-pen hold in the right hand. The pointed objects were then marked by the experimenter on the transparency. The left hand rested on the left leg.

(2.2) *Left-side stimulation and object pointing condition*. This condition was similar to the baseline condition with the exception that the left patients' arm was passively moved.

(3.1) *Baseline object reaching condition*. Patients were required to 'touch' the objects with the index finger of the right hand when the stimuli were presented in the near space, or by using a 140 cm stick when stimuli were presented in the far space. The left hand rested on the left leg.

(3.2) *Left-side stimulation and object reaching condition*. This condition was similar to the baseline condition with the exception that the left arm was passively moved.

2.4.2. Line bisection task

(1.1) *Baseline perceptual line bisection condition*. A laser pointer, moved by the experimenter, projected on the panel a red spot of diameter 4 mm. Patients were first asked to report the presence of the laser spot. When the laser spot was actually detected, it was smoothly moved along the horizontal line projected on the panel at the gaze level, with a constant velocity of 2 cm/s, in a direction opposite to the starting position. The experimenter started from the right extremity of the line in half of the trials and from the left in the other half of trials. Patients were instructed to verbally report when the red spot crossed the midpoint of the line. The experimenter measured the distance of the red spot from the right extremity of the line. Possible directional corrections made by patients after the line midpoint judgement were allowed and registered as a final response. There was no time limit. There were six trails for each length of the line. In this condition patients' left arm was kept lying on the left leg.

(1.2) *Left-side stimulation and perceptual line bisection condition*. This condition was similar to the previous one with the exception that the left arm was this time passively moved.

(1.3) *Right-side stimulation and perceptual line bisection condition*. This condition was similar to the baseline condition with the exception that, during the task, the right arm was passively moved.

(2.1) *Baseline line bisection pointing condition*. Patients were required to point the midline of the line by means of a projection light-pen hold in the right hand. The left hand rested on the left leg.

(2.2) *Left-side stimulation and line bisection pointing condition*. This condition was similar to the baseline condition with the exception that, during the task, the left arm was passively moved.

(3.1) *Baseline line bisection reaching condition*. Patients were required to bisect the lines presented in the near space with the index finger of the right hand or by using a 140-cm stick for the lines presented in the far space. The left hand rested on the left leg.

(3.2) *Left-side stimulation and line bisection reaching condition*. This condition was similar to the baseline condition with the exception that, during the task, the left arm was passively moved.

In order to avoid possible differences in posture related to the pointing and the reaching responses, patients were instructed to initiate the movement with their right hand close to the body midline.

3. Results

Three different ANOVAs were performed, one for each hypothesis put forward in the present study. One aim was to verify the effect of left and right-side *passive* activation on visual neglect. For this reason, two 2×3 ANOVAs were performed, one on the results obtained in object naming task and the other in perceptual line bisection task, with the following main effects: space (near and far) and condition (baseline, left stimulation, right stimulation). Besides the analysis of variance, pairwise comparisons using the Newman–Keuls test were conducted whenever necessary. The level of significance was always set at 0.05.

3.1. Object naming task

The dependent variable was the number of incorrect responses, that is omission errors. The analysis was performed on the percentages of target stimuli omitted. Condition was the sole significant factor ($F(2,14) = 25.45$; $P < 0.00002$). Post hoc comparison revealed a reduction of omissions in left arm movement (30%) as compared to baseline (48%, $P < 0.0001$) and right arm movement conditions (44%, $P < 0.0002$). The last two conditions did not differ significantly. All patients showed the effect.

3.2. Perceptual line bisection task

The dependent variable was the mean of percentages of displacement errors (displacement/line length%) for each condition, whereby the displacement errors were calculated in millimetres. Displacement to the right of the line objective midpoint is indicated with the '+', whereas the sign '−' indicates leftward displacement.

Only the main effect condition was significant ($F(2,14) = 15.22$; $P < 0.0003$). Post hoc comparisons showed that left arm movement significantly reduced neglect (3%) with respect to baseline (7%, $P < 0.0005$) and right arm movement (8%, $P < 0.0007$) conditions. All patients showed the effect. In contrast, there was no difference between the results obtained in the baseline and right arm movement conditions.

Another aim of the present study was to assess the possibility that (a) a *passive* left arm movement may reduce neglect when it is associated to simultaneous active right arm movement, and (b) the improvement should manifest itself more in the near than in the far space, with the exception of the condition in which the far space can be reached by a stick that extends the peripersonal space in the far space. For this reason, two repeated $2 \times 2 \times 2$ measure ANOVAs were performed, one on object cancellation task and one on line bisection task, with the following main effects: type of movement (reaching and pointing), space (near and far) and condition (baseline and left stimulation).

3.3. Object cancellation task

The main effect condition was significant ($F(1,7) = 40.66$; $P < 0.0003$). All neglect patients showed a significant reduction of omissions while the left arm was passively moved (25%) with respect to baseline condition (40%). There was no difference between pointing (33%) and reaching responses (30%) and between near (30%) and far space (33%). The interactions space × condition and type of movement × condition were not significant. The interaction type of movement × space was significant ($F(1,7) = 7.15$; $P < 0.03$). Post hoc comparisons showed that neglect was more severe in the far (38%) than in near space (28%) ($P < 0.04$) when patients were required to point objects with the laser pointer, whereas the difference between far and near disappeared (28% vs. 31%) when the patients had to reach objects by means of a stick.

3.4. Line bisection task

The main effect condition ($F(1,7) = 20.61$; $P < 0.002$) was significant. Neglect patients showed a significant reduction of rightward displacement when the left arm was passively moved (3%) with respect to baseline condition (8%). Seven patients showed the effect. No other main effect or interaction was significant. In particular no main effect of space (6% vs. 5% for near and far space, respectively) and of type of movement (4% vs. 7% for pointing and reaching responses, respectively) was found.

Finally, another aim of the present study was to assess whether a left-side *passive* movement without a corresponding right hand movement was more effective than a left-side *passive* movement with a corresponding right hand movement. To this aim, two repeated 2×3 measure ANOVAs were carried out, one on line bisection task and one on object task, with the following factors: space (near and far) and condition (left-sided stimulation/perceptual task, left-sided stimulation/pointing task, and left-sided stimulation/reaching task). Both in the first and in the second analysis, factors or interactions were not significant.

4. Discussion

Unilateral left neglect is one of the best predictors of poor functional recovery following stroke [7,14,20,32]. A temporary recovery of neglect can be induced through a neurophysiological manipulation [3], or through a specific manipulation of the experimental tasks, aimed at producing an activation of the damaged space representation.

One of this manipulation can be that of limb activation, i.e. to induce patients to make even small movements with some part of the left side of their body [21,22,26–30]. However, according to the Robertson and North's study [28], the movement should be active because a *passive* left limb activation did not produce an amelioration of neglect.

The lack of a neglect improvement in Robertson et al.'s study can be explained by considering that a *passive finger* movement might be too weak to compete with an active right hand movement. This prediction was confirmed by the results of the present study that show how an uneven competition between the two sides of space can be reduced by using a more salient movement, like the abduction and adduction of the left limb. When the left arm was passively moved and the right hand was performing pointing or reaching tasks, an amelioration of neglect was found. Indeed, in these conditions the results showed a significant reduction of omissions and of the rightward bisection displacement with respect to baseline conditions. Moreover, it is worth noting that the improvement found after the left-side passive movement in motor tasks (i.e. pointing and reaching tasks) was not significantly different from the improvement found in perceptual tasks (object naming and perceptual line bisection tasks). This means that the *passive* movement used in the present study is strong enough to compete with the activation of the right upper limb induced by reaching and pointing responses.

The temporary recovery of neglect found in the present study cannot be explained by an increase of the level of arousal produced by a *passive* movement. Fleet and Heilman [12] (also Ref. [31]) showed that neglect might be increased by reducing arousal and decreased by increasing arousal. In other words, in patients with a lesion in the right hemisphere, which it is known to produce decrements in the arousal system [8,18], limb movement might render patients more aroused, and improving in this way left-sided stimulus detection. However, the general increment of arousal induced by an arm movement cannot explain our results, because, if this is the case, amelioration should be found also after *passive* right limb activation. In contrast, in the present study a *passive* movement of right arm failed to improve left neglect: the performance in the perceptual tasks during *passive* right arm activation was not significantly different from that obtained in the baseline condition.

The absence of any significant difference between omissions made under right hand activation and those made in the baseline condition, suggests that patients impaired performance on the contralesional space was not exacerbated by a right limb movement. This result is in agreement with Mattingley et al.'s study [22] showing that ipsilesional limb activation often fails to exacerbate the detection of contralesional targets. The same result was found by Robertson and North [29] in a task where neglect patient was required to read all the numbers and letters on a sheet of paper. In this study, omissions under right hand activation did not differ significantly from those found in the normal condition, in which no-movement was involved. At first these results may seem contrary to the competition model of neglect [9,10], which assumes that competition should become more uneven when the right side of the space is further activated by a right limb stimulation. However, it is possible that due to patients' lesion, the right side of the space was already maximally activated, such that right limb movement could not exert any further activation.

The results of the present study clearly show that abduction and adduction of the left hand is per se sufficient to partially overcome visual neglect. One way to interpret this robust effect of left forearm stimulation is by considering the contribution of proprioceptive information in building up space representation. Space representation is based on the balance between the afferent sensory input, including visual, vestibular and proprioceptive information, from the two sides of the space and body. In neglect patients, visual input presented in the contralesional space evokes a weak representation of the left side of space. In addition, the left side of the body is less represented comparing to the right side, due to the primary sensory deficits. It is worth noting that most of neglect patients present a left hemiplegia and somatosensory deficit, which may be responsible for the decrease level of limb position activation.

In the present study, we have tried to obtain the activation of the proprioceptive map whose level of activation was diminished by the brain lesion. Proprioceptive information may be rendered more salient by activating an increased number of proprioceptive receptors involved in a movement, like the skin receptors, muscle spindle receptors, Golgi tendon organs, and receptors in joint capsule.

As far as the skin receptors is concerned, Cohen et al. [5] found that kinematically similar active and *passive* movements produce a similar activation at the peripheral level (tactile receptors) and in the primary somatosensory cortex (SI). Of course, the entity of activation depended on the extension of the region of the skin stimulated. The *passive* abduction and adduction of the upper limb used in the present study involve the skin of the hand, forearm, arm and shoulder, whereas the *passive* movement of the index and the middle fingers, used in Robertson and North's study [28] involves only the skin of the region of the hand. Thus, it becomes obvious how in our study the extension of the stimulated skin is bigger than in Robertson et al.'s study, and as a consequence more proprioceptive information arrives to the somatosensory cortices.

In addition, proprioceptive information can be rendered more salient by increasing the number of muscle spindle receptors and Golgi tendon organs as well as the numbers of joints involved in the movement. The *passive* movement used in the present study involves muscles of arm, forearm and shoulder as well as elbow and shoulder joints. In contrast, in Robertson and North's study [28] the number of muscles and joints involved in the passive movement were very few.

Therefore, if the amount of proprioceptive information arriving to the brain from the periphery depends on the extension of the stimulated skin, number of muscles and joints involved in the movement, then we can conclude that more peripheral sources of proprioceptive signals are involved in the abduction and adduction of the arm comparing to that involved in fingers movement. Proprioceptive information from the body is mainly relayed to the somatic sensory cortices, which include S-I, S-II and the somatic sensory association area, which is located in the posterior parietal cortex (Broadmann's areas 5 and 7). Therefore, the extension of the cerebral areas involved in the limb activation is wider than that involved in finger movement. Thus, the greater activation of the right somatic sensory cortices and the associative somatic cortex renders the competition with the left sensory-motor cortex, activated by the active right arm movement, less uneven, and as results stimuli presented in the impaired contralesional space are better detected. Therefore, it seems that the entity of somatosensory input produced by left arm passive movements is critical to the improvement of left-side stimulus detection.

It seems clear how the integration of visual and proprioceptive information is important in building up an unitary representation of the space. This integration probably occurs at the level of the parietal lobe, a crucial area for cross-modal and sensorimotor integration in the brain (for a review, see Ref. [24]). This sensory integration, however, is not segregated in a specific sector of the space, for example in the peripersonal space, as it has been hypothesised in Section 1. This prediction was based on the assumption that limb movement activates peripersonal space, i.e. space reachable by the hand, more than extrapersonal space. However, the results of the present study showed that the proprioceptive stimulation reduced neglect for stimuli presented in the peripersonal as well as in the extrapersonal space in agreement with Robertson et al.'s study [30]. Their findings showed that limb activation significantly improved neglect in three different sectors of space: body space, peripersonal space (near space) and extrapersonal space (far space).

This finding can be explained if we consider the functional properties of peripersonal space. Recent studies [11,19] have shown that peripersonal space is not activated by a simple movement executed by the hand, but only by a specific movement aimed at reaching objects in the space. For instance, it has been shown that the dynamic properties of peripersonal space, i.e. space expansion and contraction, depend upon the use of the tool, aimed at physically reaching distant objects, and it does not merely result from motor activity. In these studies, the simple manipulation of a tool, without any intention to use it, did not modify the representation of the body schema and the representation of the peripersonal space. In our experiment, limb abduction and adduction was not a self-initiated movement aimed at physically reaching distant objects. Thus, it is possible that a passive movement is not able to selectively activate the peripersonal space; instead, the activation extends its effect to both peripersonal and extrapersonal space.

The functional properties of the peripersonal space have been also confirmed in the present study, whereby it has been shown that the use of the stick, and not that of a light pen, is able to modify the peripersonal space, i.e. it extends the peripersonal space to the far space. Indeed, patients were more impaired in the far than in the near space when they pointed objects with a light pen; however, when they reached objects in the far space by using a stick, neglect in far space was less severe and its severity was comparable to that found in the near space. This effect manifested itself only in cancellation tasks; in the line bisection tasks there was not a differential impairment in the near and far space and no effect related to the type of responses, i.e. pointing vs. reaching responses. This might be explained by considering that, at least in our study, neglect was more severe in the cancellation tests than in the line bisection tests. Therefore, it is possible that the low sensitivity of line bisection test to neglect is responsible of the absence of a differential effect of the stick and light pen on the extrapersonal space.

In conclusion, left limb proprioceptive information can activate right hemisphere and thus modulate left neglect, even in presence of left hemisphere activation induced by right limb sensorymotor information. However, the entity of improvement is strictly related to the entity of proprioceptive signals specifying left hand position and manifests itself both in near and far spaces.

One question which needs to be addressed in a near future is whether the improvement found after a passive activation of the contralesional limb has a long-lasting effect. If this is the case, it is possible to hypothesise that after a repeated passive limb activation we can obtain a permanent amelioration of the neglect symptoms in those patients with a severe hemiplegia. This possibility is particularly relevant in terms of rehabilitation prospective because a crucial limitation of the standard self-generated limb activation, as a rehabilitative tool, is that it can be used only in patients without hemiplegia [30].

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