

# MULTIPLE REFERENCE FRAMES IN NEGLECT? AN INVESTIGATION OF THE OBJECT-CENTRED FRAME AND THE DISSOCIATION BETWEEN “NEAR” AND “FAR” FROM THE BODY BY USE OF A MIRROR

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## ABSTRACT

In this single case study of a man (AE) who suffered a right hemisphere stroke we showed the co-existence of neglect within different spatial frames: (a) In left hemispace and (b) in ‘far’ versus ‘near’ space, both as defined from the patient’s viewpoint, as well as (c) for the left side of an object (as defined from an object-centred view). In the experiment, AE’s latencies to name the colour of two cubes, each located in one hemispace, were measured. In some conditions, the cubes were placed on a table but in other conditions each cube was held in one hand of an experimenter who could either face the patient or show the cubes while her back was turned towards him. One prediction was that AE would show longer latencies for cubes in left hemispace; however, if object-centred neglect also occurred, then latencies should be even longer for cubes held in the experimenter’s left hand. In order to reveal the presence of neglect for ‘far’ versus ‘near’ space, the cubes could also be positioned either near to (i.e. reaching distance) or far from the patient (i.e., several metres out of reach), by moving the table or the experimenter. Finally, in some conditions, AE looked at the cubes into a mirror that was positioned far away from his body. Because external objects seen in a mirror can be ‘near’ the patient’s body, the patient actually looked at a ‘far’ location (i.e. the surface of the mirror) to see an object that is ‘near’. The experiment confirmed the presence of all forms of neglect, since AE not only named the colour of a cube seen in his left hemispace more slowly than in right hemispace, but latencies increased for a cube held by the experimenter in her left hand and in left hemispace (both when the left hand was seen directly or as a mirror reflection). Finally, AE’s performance was worse for ‘far’ than ‘near’ locations, when the cubes were physically located near his body (i.e., within “grasping” space) but seen in the mirror.

Key words: spatial neglect, reference frames object-centred neglect, peripersonal space, mirror, hemianopia

## INTRODUCTION

As often described in the neuropsychological literature, spatial neglect is characterized by a deficit in orienting towards, responding to, and reporting stimuli that appear contra-laterally to the side of brain damage (Heilman et al., 1993). Even when left stimuli are correctly reported as present, such patients may show significantly slower response times (RTs) to left targets than to targets that occupy right-sided locations (Posner et al., 1984, 1987). The currently accepted account of neglect is that the neglect “syndrome” reflects an

underlying problem in the visual attention system that selects areas of space occupied by objects for detailed perceptual processing (Driver and Baylis, 1998; Vallar, 1998). Indeed, the syndrome occurs after lesions to areas that have been clearly linked to the functioning of the attentional system in normal individuals. For example, normal subjects show brain activation in the parietal lobe of the right hemisphere when engaged in visual tasks that require shifts of attention to either side of space (Corbetta et al., 1993; Posner and Raichle, 1997); correspondingly, left-hemisphere neglect resulting from a lesion to the right hemisphere is both more common and severe in kind than right-hemisphere neglect after lesions to the left hemisphere (Heilman et al., 1993).

However, in the context of perception and neglect the term "left hemispace" is not unambiguous, since it is known that the human visual system makes use of multiple frames of reference. Several studies have shown that neglect symptoms can occur with respect to spatial axes other than the one based on the gravitational axis centred on the patient's body. It turns out, for example, that neglect symptoms can also exist for objects appearing in 'near' as opposed to 'far' space, when taking the patient's body location as the origin (Halligan and Marshall, 1991). This dissociation further extends our concepts of reference frames, since it would seem to imply a topological representation of surrounding space as concentric, annular, spatial regions. The traditional view of neglect, in contrast, seems to rely on the partition of space into binary patches (e.g., left/right, above/below) across the boundary established by one linear vector within a "Cartesian" space. Specifically, Halligan and Marshall (1991, 1995) found that neglect can occur for objects in the immediate surrounding to the patient's body but it is reduced when the object is located at distant locations ("walking distance"); indeed, they observed an abrupt change in neglect for objects located within 'near' or "peripersonal" space versus when these occupied "out of reach" locations. Moreover, Cowey and colleagues (1994, 1999) found the reversed dissociation in a group of patients; namely, longer distances away from such "peripersonal" space increased the patients' degree of neglect. Similarly, Chatterjee et al. (1999) described several patients showing dissociations along a 'near-far' partition of space; of their 8 patients, 5 showed greater neglect for 'near' than 'far' space whereas the other 3 patients showed greater 'far' than 'near' neglect.

We surmise that neglect along the 'near-far' direction may reflect damage to spatial reference frames that are used by action-based attentional mechanisms. Specifically, we can distinguish one such spatial frame based on hand movements (i.e., reachable versus unreachable space; or a "grasp system", cf. Ward, 1999) and another mechanism of attention that defines external positions for the control of eye fixations towards external objects (Rizzolatti and Gallese, 1988). The latter reference frame would not partition space in the same topological space as the frame that defines external positions for the control of hand movements (e.g., reaching and grasping) since gaze does not require actual contact between the object (e.g., the moon) and the observer's body. Moreover, the same system that controls orienting of gaze, or a system similarly organized, could control action of other body parts, like the index finger, for orienting to targets in situations that do not require any contact between the observer's body

parts. Therefore, we would assume that a spatial frame supporting deictic actions would be indistinguishable from the spatial frame underpinning the control of eye scanning and fixations and would show an absence of topological boundaries. Interestingly, Cowey et al. (1994, 1999) asked patients to point with a laser spotlight to the centre of a line (at variable distances from the patients) and found that they were increasingly impaired as lines were located further away; interestingly there was no evidence of a sudden increase in the displacement of centre when the maximum 'reaching distance' was exceeded.

We may also note here that 'far' locations require movements of the eyes (or pointing with the index finger) towards angular locations that are higher in the viewer's space than 'near' locations (cf. Shepard and Hurwitz, 1985). In this respect 'near' and 'far' neglect may represent a form of "altitudinal neglect" (Butter et al., 1989; Rapcsak et al., 1988) or neglect for objects located in the upper or lower regions of space. Several patients have been described so far with this form of neglect, although the connection between this and 'near-far' neglect has not been yet explored. 'Far' space representation may then depend more than 'near' space representation on attentional mechanisms that control eye movements and scanning to locations in the upper hemispace. Specifically, Rizzolatti and Gallese (1988) have proposed that area 8 or the frontal-eye-fields, an area of the brain known to programme saccades in primates (Bruce and Goldberg, 1985), would be involved in 'far' space representation.

Neglect would also seem to occur within an object-based reference frame (Behrmann and Tipper, 1994, 1999; Driver and Halligan, 1991); that is, for the region or a target located on one side of an object. Objects can have sides or surfaces defined by their intrinsic axes (for instance, humans have left/right, front/back sides), independently of the side of space defined by the observer's viewpoint. In one experiment, Behrmann and Tipper (1994) showed to neglect patients a schematic barbell, where the disks had different colours, which was then rotated slowly through 180°. The patients neglected the colour of the bell that was associated to the left side of the object even in its new right hemispace location. In contrast, when a bar did not explicitly connect the two sides of the object, the patients showed neglect only for the bell in the left hemispace, regardless of the previous presentation and rotation. Moreover, in one experiment, a patient with a left lesion and right hemispace neglect dyslexia (i.e., who made errors with the endings of words) would neglect the end of a word even when it was presented in mirror fashion (Caramazza and Hillis, 1990a, 1990b).

In the present study, we assessed whether the neglect observed in a patient (AE) was specific to one reference frame or whether it would be best interpreted as the concurrence of neglect symptoms defined by different spatial reference frames. Coloured cubes were used as target objects in a colour-naming task. On each trial one cube was always to his left and the other cube to his right. The patient's task was simply to close his eyes (while a new pair of cubes was arranged) and then open them and report the cubes' colours. The patient was instructed explicitly that on each trial there would always be two cubes. In previous search tasks we had discovered that AE would neglect present left-sided targets only when there were a certain probability that a target would not be present. In contrast, in search tasks where he was told that the target was

always present, AE could always find and point to the target but RTs to left-hemisphere targets were increasingly lengthened with increasingly left-sided targets. Indeed, it is well known that when neglect patients report left targets they tend to do this at significantly slower response times (RTs) than for targets that occupy right-sided locations (e.g. Behrmann et al., 1997).

During the experiment, the cubes were either held in the hands of the experimenter or placed on a table. Also, when the experimenter held the cubes in her hands, she either faced the patient or turned her back towards the patient, so as to dissociate the spatial frame centred on the experimenter from the one centred on the patient. If AE showed neglect both in viewer-centred and object-centred space, then neglect or slowing of RT should be worst for the cube held in the experimenter's left hand when this hand was also located within left hemisphere from the patient's viewpoint (that is, when the experimenter had her back turned). In addition, we varied the positions of the experimenter and table by placing these either near (i.e. within reaching distance) or far from the patient (i.e., several metres away). Clearly, such a manipulation allowed us to compare 'near' and 'far' neglect.

Most importantly, we repeated the above manipulations in a condition in which the patient looked into a mirror positioned several metres away from him. In this manner, a target object could be presented near the patient's body although the patient would be actually looking at a far region of space where the mirror was located. It is a well-known property of mirrors (cf. Gregory, 1997) that they extend space by doubling linear perspective; that is, the image of the cube would be twice as distant as the far mirror, while the object could actually be at reaching distance. Current descriptions of neglect along "radial" or polar positions distinguish between a "peripersonal" and "extrapersonal" space but they remain unclear about whether (a) these spatial descriptions apply to the region of space where the eyes scan and explore for a target or (b) to regions of space that are distant (unreachable) or close (reachable) for the patient's hands. In the conditions in which AE looked at the cubes via the mirror we could distinguish whether colour naming latencies varied as a function of (a) "physical" 'near' or 'far' space or (b) visually scanned 'near' or 'far' space. Moreover, another well-known property of mirrors (Gregory, 1997) is that they "reflect" an object so that when this shows its front side to the mirror, its left side will still be seen on the left side of the mirror (whereas when an object rotates, its left and right sides switch positions for a static observer). Hence, if a patient neglects the left side of an object (in this case, the experimenter's left hand), we would expect not only differential effects of whether the experimenter faced the patient or turned her back but also of whether the hand was looked at directly or as a reflection in the mirror.

## MATERIALS AND METHODS

### *Subject*

AE was a 64 year old, right-handed, Norwegian male who suffered a cerebrovascular accident in the Autumn of 1997, which affected the occipital and parietal areas of the right hemisphere as well as the thalamus on the same side, according to neuroscans performed at the Regional Hospital of Tromsø, in northern Norway. As a result of his stroke, AE showed a left homonymous hemianopia as well as left hemisphere neglect in standard neurological

tasks (e.g., line bisection, cancellation tasks, search of target shapes among distracters, clock drawing). In addition, AE was left hemiparetic and confined to a wheelchair. His neglect and hemiparesis made it impossible for him to live independently. AE had also as subtle problem in form discrimination, as revealed in difficult versions of cancellation task where some of the distractors were very similar to the target (e.g., Weintraub and Mesulam, 1987). Colour naming was normal according to standard tests performed at the Regional Hospital. Also according to standard neurological testing, AE showed normal pursuit and saccades towards visual stimuli presented outside the area of scotoma. The patient was a permanent resident of a nursing home in Tromsø and this study was conducted there during the autumn of 1998. In separate sessions, two healthy Norwegian males, 54 and 69 years old, performed the same tasks, in the same order as AE. One control subject had the same educational level of AE, whereas the other control subject had received university level education. AE died in the autumn of 2000.

#### *Apparatus and Stimuli*

Four cubes of 3.8 cm in side length were used as the target objects. Each cube differed in colour: yellow, green, blue and red. All objects were presented statically; that is, lying on a table (74 cm high) or placed in the experimenter's open palms at about the same height and at the same distance relative to each other as when they were presented on the table. The table or experimenter could be located either 'near' or 'far' from the patient. In the 'near' condition the table was placed in front of the patient's wheelchair so that each cube was at about 50 cm from AE's body; similarly, in the 'near' condition in which the cubes were held by hand, the experimenter sat on a chair in front of the patient, a cube in each hand and at about the same position it would have appeared on the table. Alternatively, the experimenter stood behind the subject holding the cubes at the level of his shoulders. In the 'far' condition the table was placed further away from the patient at a distance of 3 m. Each cube of a pair was always positioned approximately 25 cm to the left or right of the patient in the near condition, whereas the distance was doubled (50 cm) in the 'far' condition (so as to, roughly, maintain the same visual angle between them). Finally, some conditions required the patient to view the cubes in a mirror (47 × 87 cm). In these conditions, another experimenter held the mirror at a position appropriate for AE to achieve full view of the cubes. The mirror was always located at the same distance the cubes would have occupied in the 'far' condition. In each 'mirror' condition, the experimenter stood close behind the patient while holding the cubes in full vision at the patient's sides. The experimenter could stand either in the same orientation as the patient, so as to appear frontally in the mirror, or with her back turned.

#### *Design*

The experiment consisted of 8 conditions, which are illustrated in Figure 1 (Conditions A to H). In the first condition the patient viewed the cubes on a table and 'near' his body (Condition A). In the second condition the patient viewed the cubes on a table and 'far' from his body (Condition B). In the third condition the patient viewed the cubes held by the experimenter while she sat 'near' the patient, facing him (Condition C). In the fourth condition the patient viewed the cubes held by the experimenter while she sat 'far' away and facing the patient (Condition D). In the fifth condition the patient viewed the cubes held by the experimenter while she sat 'far' and turned her back towards the patient (Condition E). In the sixth condition the patient viewed the cubes in the 'far' mirror while these were positioned on a 'near' table (Condition F). In the seventh condition the patient viewed the cubes in the 'far' mirror while the experimenter facing him held the cubes in her hands (Condition G). In the eighth condition the patient viewed the cubes in the 'far' mirror while the experimenter turned her back towards the patient and held the cubes in her hands (Condition H). In the last three conditions another experimenter checked that the patient looked at the cubes only in the mirror and not directly. There were a total of 192 trials, in which each of the eight conditions was presented 24 times, 12 times in each of two blocks. Each trial within a block presented a different combination of cubes' colours

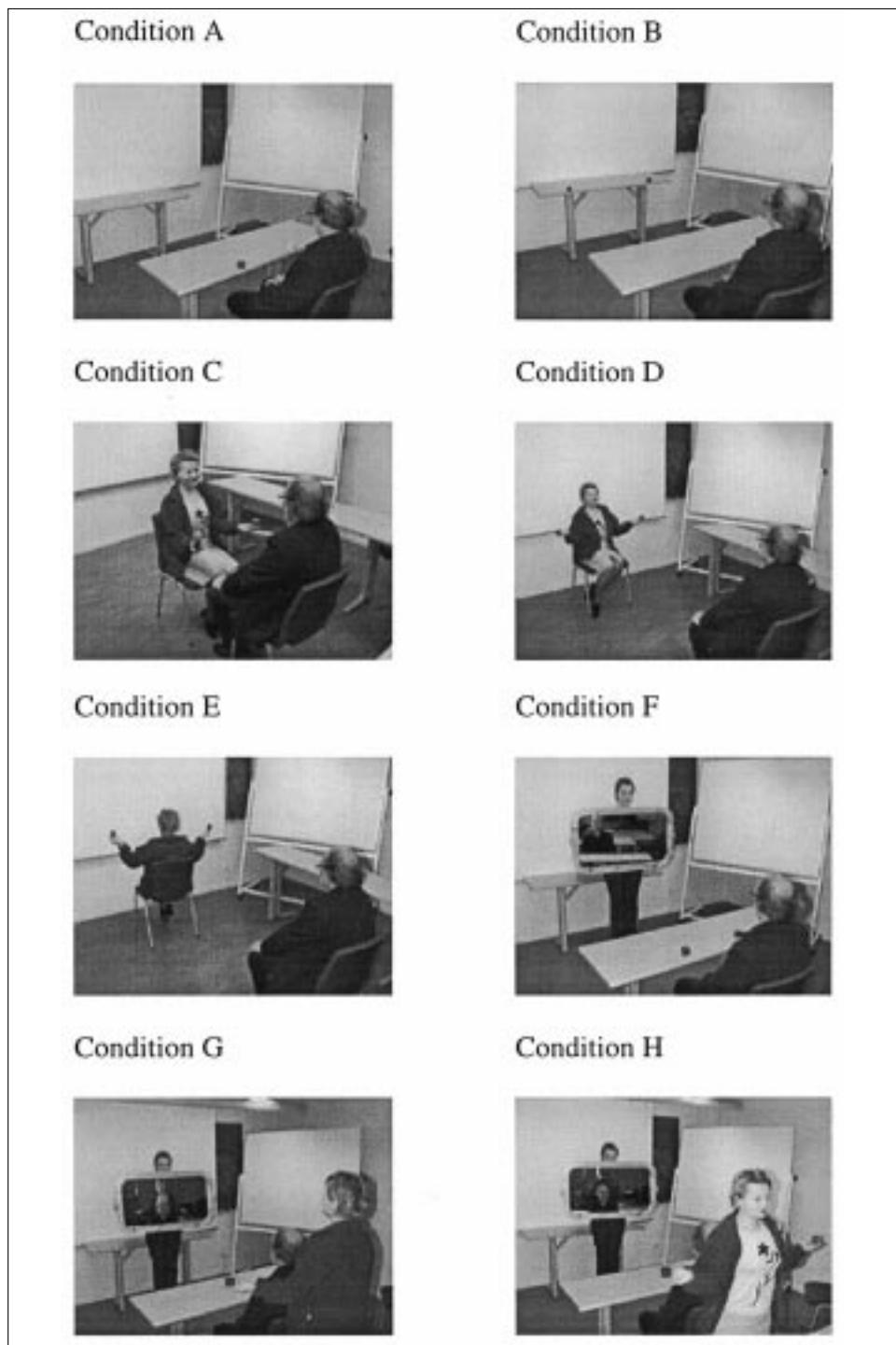


Fig. 1 – *The different conditions used in the experiment (photos by Bruno Laeng).*

and left/right positions. The first half of the experiment consisted in testing one block of 12 trials in each of the conditions (e.g., from A to H); in the second half of the experiment the remaining blocks of each condition followed each other in inverse order (e.g., from H to A) in order to balance practice and fatigue effects. Notice that in our design we did not include all the possible combination of the variables under investigation. In other words, we did not orthogonally balance all factors. The main reason for it was that, whereas it is a rather straightforward matter to dissociate the two action-based mechanisms by showing in a simple mirror visually near objects that are manually far, the opposite situation of showing objects that appear on a surface that is within reach despite the physical stimuli being far would require considerably more complex apparatus (e.g. a video presentation system; and for a more truly ecological situation, in which the stimuli themselves appear "graspable", holographic presentations).

#### *Procedure*

AE sat at all times in his wheelchair. The experimenter explained at the beginning of the session that on each trial two cubes would be presented and that AE's task was to name the colour of each cube as quickly as possible. At the beginning of each trial AE was requested to close his eyes while the experimenter arranged the test situation according to the specific trial's condition. Once all was in place, the experimenter told AE to open his eyes and name each cube's colour without any constraint on which cube should be named first. At the same time two other experimenters measured with stopwatches from the time in which AE opened his eye to the time he named the colour of each cube. Errors in naming a colour were also registered. At the beginning of each block, AE was told whether the experimenter would hold the cubes in her hands or whether the cubes would lie on the table, and in the mirror blocks was instructed to look in the mirror.

## RESULTS

AE never failed to report a colour for one of the cubes; however, in a few instances (less than 1% of the trials) he named a wrong colour (i.e., 'green' instead of 'blue'). One of the controls also made the same colour naming error twice. RTs in these occasional wrong trials were excluded from the RT analyses of all subjects. Table 1 summarizes AE's RT performance in each experimental condition. Table 2 summarizes the two control subjects' performance, respectively, in the same experimental conditions. As is common practice in neuropsychology, we considered a patient's performance abnormal when it was more than 2.5 SDs away from the control subjects' average performance. Hence, in Table 3 we list the difference between AE's mean RT performance and the control subjects' averaged RT performance, this difference being expressed in units of standard deviations of the normal performance.

Given that the separate variables manipulated in the experiment were not orthogonally balanced, it was not possible to analyse all factors and their interactions in a single repeated-measures ANOVA. Therefore, separate ANOVAs were performed to test the comparisons of most interest. Whenever possible, interactions between different within-subject factors were examined.

#### *Response Times*

First of all, we assessed whether AE showed a difference in reporting a cube's colour depending on (a) the position of the cubes from the patient's own

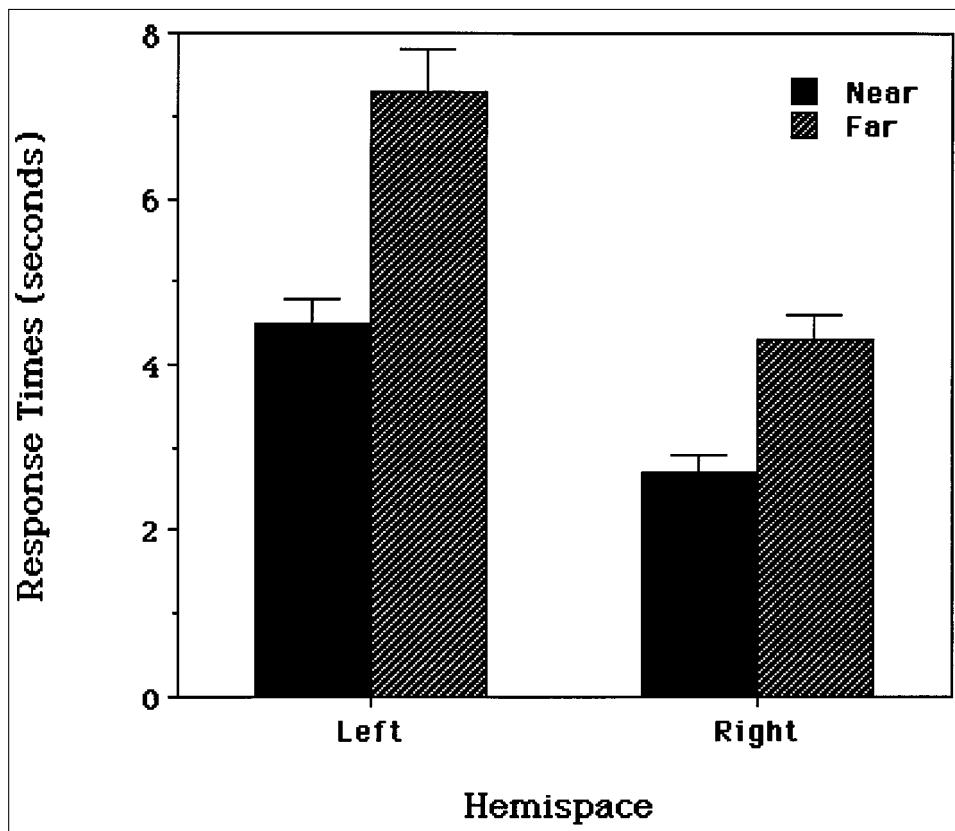


Fig. 2 – Mean RTs and SEs for ‘near’ and ‘far’ locations in the ‘left’ and ‘right’ hemispheres.

perspective, or hemispace and (b) the cubes’ distance in terms of length of line of sight, or viewing distance (for this analysis we excluded the conditions that made use of the mirror, i.e. F, G and H in Figure 1, which we considered in the final two analyses). Thus, this ANOVA had hemispace (left/right) and viewing distance (near/far) as the within-subject factors. As shown in Figure 2, the colour of the ‘left-hemisphere and far’ cube was named the slowest (mean RT = 7.1 sec; SD = 3.8). The colour of the ‘left-hemisphere and near’ cube (mean RT = 4.3 sec; SD = 2.0) and that of the ‘right-hemisphere and far’ cube (mean RT = 4.2 sec; SD = 3.1) were named at the same speed. The colour of the ‘right-hemisphere and near’ cube was named the fastest (mean RT = 2.7 sec; SD = 1.4).

AE took almost twice as long to report the colour of a cube in his left hemispace (mean RT = 6.6 sec; SD = 4.9) as he did to report the colour of a cube seen in his right hemispace (mean RT = 3.9 sec; SD = 3.0). This main effect of hemispace was highly significant,  $F(1, 190) = 79.1$ ,  $p < 0.0001$ . Finally, AE was slower in reporting the colour of cubes seen at a far distance (mean RT = 5.8 sec; SD = 4.7) than when the cubes were near (mean RT = 3.6 sec; SD = 1.9). This main effect of viewing distance was also significant,  $F(1, 190) = 13.0$ ,  $p < 0.0004$ . Importantly, the analysis confirmed that the interaction

of hemispace and viewing distance was significant,  $F(1, 118) = 7.1$ ,  $p < 0.01$ . Separate t-tests confirmed that AE was significantly slower in the “left-hemispace and far” condition than in all the other conditions that is, the “left-hemispace and near” condition,  $t(59) = 1.97$ ,  $p < 0.05$ , the “right-hemispace and far” condition,  $t(59) = 5.23$ ,  $p < 0.0001$ , and “right-hemispace and near” condition,  $t(59) = 5.16$ ,  $p < 0.0001$ . In addition, a Scheffé’s test comparing RTs to near and far position in the left hemispace only confirmed that cubes located in the far position were responded more slowly than cubes located in the near position, Difference = 2.2, Critical Difference = 1.2,  $p < 0.0003$ . Interestingly, another Scheffé’s test comparing RTs to near and far position in the right hemispace also revealed that AE named the colours of cubes located in the far position more slowly than when cubes were located in the near position, Difference = 0.9, Critical Difference = 0.7,  $p < 0.01$ .

The same analysis was performed separately on the data of Control 1 and Control 2. In both cases, the analyses revealed no significant difference in RTs for either of the main effects or for the interaction of the two. AE was overall slower than his control subjects in reporting the cubes’ colours in either hemispace (see Tables 1, 2, and 3). A look at Table 3 shows that the difference between the patient’s performance and that of the control subjects was always greater for cubes located in left hemispace than for those in right hemispace.

The second type of ANOVA that we performed assessed whether AE showed evidence of object-centred neglect. In this case, the ‘object’ was the person holding a cube in each hand. By turning around so as either to face the patient or to show her back towards the patient, the cubes appeared either in the patient’s left or right hemispace as well as in relation to the left and right sides of the experimenter. This ANOVA was based on AE’s performance in the two conditions D and E (see Figure 1) and included hemispace (left/right) as one within-subject factor and body orientation (front-towards-patient/back-towards-patient) as another within-subject factor. Figure 3 illustrates the patient’s performance in the hemispace and body orientation conditions. The analysis of variance showed an interactive effect of body orientation with hemispace,  $F(1, 46) = 11.7$ ,  $p < 0.001$ .

TABLE 1  
AE’s Mean RT (SDs), in Seconds, in Each Experimental Condition

Condition	Viewing distance	Body orientation	Mirror	Hemispace	
				Left	Right
A	Near	—	No	4.0 (1.7)	2.5 (1.4)
B	Far	—	No	3.3 (1.1)	2.6 (0.9)
C	Near	Front-towards-AE	No	4.9 (2.3)	3.0 (1.5)
D	Far	Front-towards-AE	No	7.3 (2.3)	4.6 (1.3)
E	Far	Back-towards-AE	No	9.5 (4.2)	3.8 (3.0)
F	Far	—	Yes	5.1 (2.1)	4.0 (2.6)
G	Far	Front-towards-AE	Yes	10.8 (6.2)	5.3 (3.5)
H	Far	Back-towards-AE	Yes	6.6 (2.0)	5.2 (1.9)

Viewing distance refers to whether the patient’s line of sight is directed to a near or far region of space. Body orientation refers to whether the experimenter (holding the cubes in conditions C, D, E, G and H) was oriented with her front towards the patient or with her back turned. In conditions F, G and H, viewing distance is far into the mirror but the cubes are located in AE’s peripersonal space (see Figure 1).

TABLE 2  
*Control Subjects Mean RT (SDs), in Seconds, in Each Experimental Condition*

Condition	Viewing distance	Body orientation	Mirror	Hemispace			
				Control 1		Control 2	
				Left	Right	Left	Right
A	Near	—	No	1.2 (0.4)	1.5 (0.5)	1.1 (0.3)	1.1 (0.3)
B	Far	—	No	1.7 (0.7)	1.8 (0.5)	1.2 (0.4)	1.1 (0.4)
C	Near	Front-towards-subject	No	1.7 (0.9)	1.6 (0.7)	1.4 (0.9)	1.5 (0.9)
D	Far	Front-towards-subject	No	1.3 (0.5)	1.5 (0.5)	1.3 (0.7)	1.1 (0.3)
E	Far	Back-towards-subject	No	1.9 (0.5)	1.9 (0.3)	1.1 (0.3)	1.3 (0.6)
F	Far	—	Yes	1.7 (0.5)	1.5 (0.5)	1.1 (0.4)	1.0 (0.2)
G	Far	Front-towards-subject	Yes	2.0 (0.6)	1.8 (0.7)	1.1 (0.4)	1.1 (0.3)
H	Far	Back-towards-subject	Yes	2.0 (0.8)	2.2 (0.6)	1.3 (0.4)	1.3 (0.4)

TABLE 3  
*Slowing of AE's Mean RT Performance (or Difference between AE's Mean RTs and the Control Subjects) Expressed in Terms of SDs Units (i.e. Differences in Mean RTs Divided by the Control Subjects' SDs)*

Condition	Hemispace	
	Left	Right
A	8.3	3.1
B	3.4	3.2
C	3.7	1.8
D	13.5	6.3
E	13.2	4.9
F	9.3	7.9
G	18.3	7.7
H	8.2	6.9

Specifically, we found that the patient was slowest in naming a cube when this was in the experimenter's left hand and her back was turned (Condition E in Figure 1) so that the left hand was located within the patient's left hemisphere (mean RT = 9.5 sec; SD = 4.3). Naming the colour of a cube held in the experimenter's right hand but while she now faced the patient (Condition D in Figure 1), so that the cube was still in the patient's left hemisphere, was achieved at a faster speed (mean RT = 7.3 sec; SD = 2.3). A t-test confirmed the difference with the previous condition,  $t(22) = 2.2$ ,  $p < 0.02$ . When the named cube was held in the experimenter's left hand and she faced the patient, so that the cube was located in AE's right hemisphere (Condition D in Figure 1), AE also was slower (mean RT = 4.6 sec; SD = 1.3) than when the named cube was held by the experimenter, now turning her back to AE, in her right hand and in right hemisphere (Condition E in Figure 1; mean RT = 3.8 sec; SD = 3.0). A t-test showed that this difference was also significant,  $t(22) = 1.7$ ,  $p < 0.05$ . The analysis of variance showed no main effect of body orientation but, as mentioned earlier, this factor significantly interacted with hemisphere. There was however a significant main effect of hemisphere,  $F(1, 46) = 93.5$ ,  $p < 0.0001$ , due to slower responses to cubes on the left (mean RT = 8.4 sec; SD = 3.6) than to cubes on the right (mean RT = 4.2 sec; SD = 2.4). When the same ANOVA described above was performed on the data of Control 1 and Control 2, this revealed no significant difference in RTs for either main effect or for the

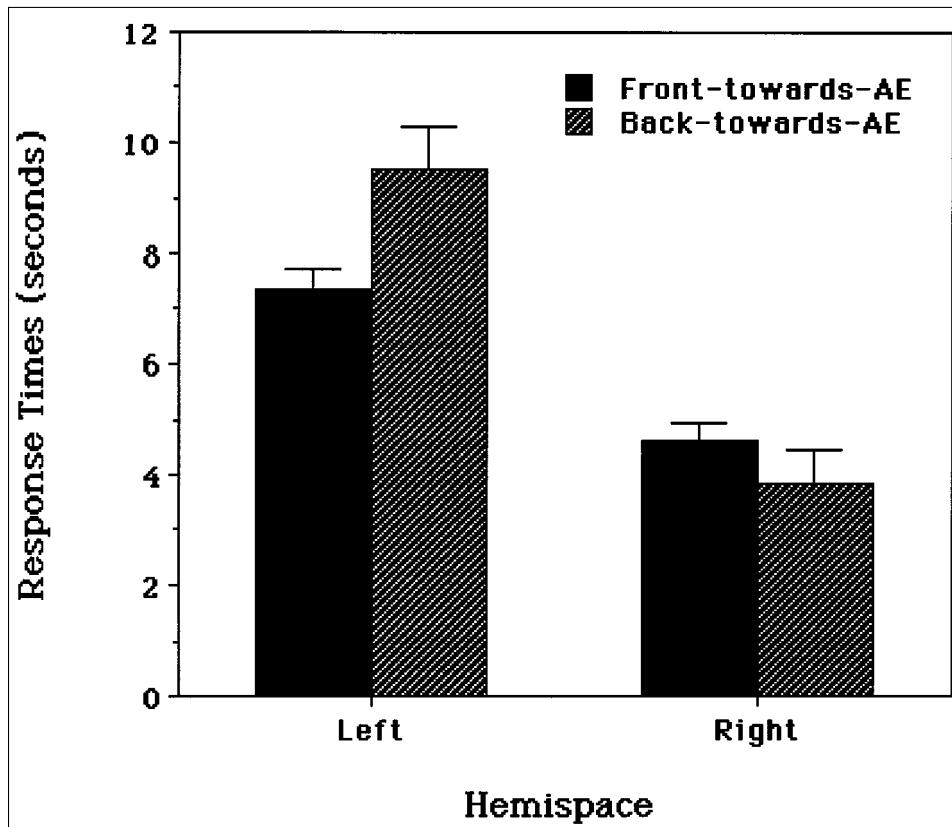


Fig. 3 – Mean RTs and SEs for 'front-towards-patient' and 'back-towards-patient' presentations in the 'left' and 'right' hemispaces.

interaction of the two for either control subject.

In the third ANOVA, we assessed the effects of the experimenter rotating her body so as to face towards the patient or turn her back while AE actually saw the experimenter's body in the mirror (conditions G and H in Figure 1 and Table 1). Specifically, we reasoned that if AE treated the image in the mirror as a reflection then we should expect AE to show his worst performance in the "left hemisphere, front-towards-AE" condition. In other words, the left hand of someone facing him in the mirror would now appear in his left hemisphere (as shown in Figure 1 condition G), whereas the left hand of the experimenter turning the back to him would now appear in the mirror in his right hemisphere (condition H in Figure 1). Thus, if we observed a reversal of the findings seen in the previous analysis (for the D and E conditions), this would be further evidence that a spatial framework based on the experimenter's body (i.e., her physical left and right hands) did modulate AE's neglect or slowness in naming "left-sided" stimuli. And indeed, as shown in Figure 4, AE was slowest (mean RT = 10.8 sec; SD = 6.2) in naming the colour of the cube held in the experimenter's left hand while she appeared facing him in the mirror (condition

G in Figure 1). A t-test confirmed that the "mirror, left hemispace, front-towards-AE" condition was slower than the "mirror, left hemispace, back-towards-AE" in which the experimenter's right hand was now seen in the mirror and in left hemispace (mean RT = 6.6 sec; SD = 2.0; see condition H in Figure 1),  $t(22) = 3.2$ ,  $p < 0.005$ . Instead, there were clearly no significant differences in speed when the named cube was held in the "mirror, right hemispace, front-towards-AE" (mean 5.3 sec; SD = 3.5) and in the "mirror, right hemispace, back-towards-AE" (mean RT = 5.2 sec; SD = 1.8). The ANOVA on AE's performance in these two conditions G and H with hemispace (left/right) and body orientation (front-towards-AE/back-towards-AE) as the within-subject factors confirmed that the interactive effect of hemispace and body orientation was significant,  $F(1, 46) = 22.4$ ,  $p < 0.0001$ . Moreover, both the main effects of hemispace,  $F(1, 46) = 62.9$ ,  $p < 0.0001$ , and body orientation,  $F(1, 46) = 4.5$ ,  $p < 0.04$ , were significant. AE was slower in left hemispace (mean RT = 8.7 sec; SD = 5.0) than right hemispace (mean RT = 5.3 sec; SD = 2.8) and when the experimenter faced him in the mirror (mean RT = 8.1 sec; SD = 5.7) compared with when showing her back (mean RT = 5.9 sec; SD = 2.0).

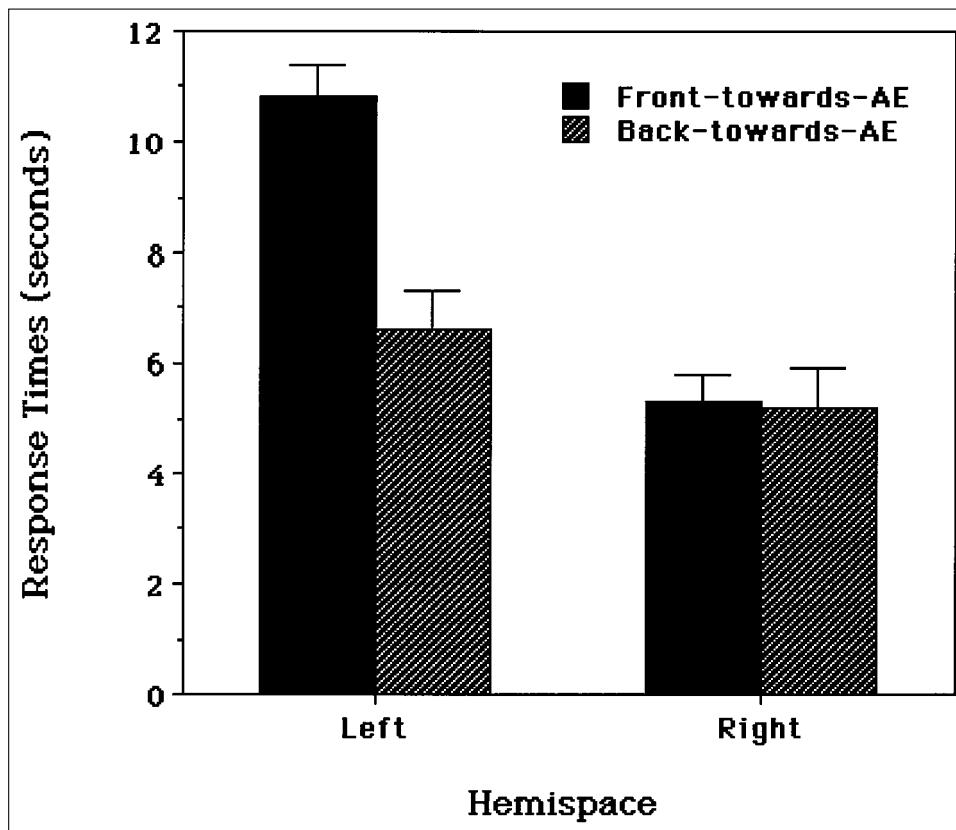


Fig. 4 – Mean RTs and SEs for 'front-towards-patient' and 'back-towards-patient' presentations in the 'left' and 'right' hemispheres in the conditions in which the patient viewed the experimenter's hands in a mirror.

When the same ANOVA described above was performed on the data of Control 1 and Control 2, there was no significant difference in RTs for either main effect or for the interaction of the two for either control subject. When we compared AE's performance to those of the control subjects, the patient was in every condition except one (condition C in right hemisphere) 3 SDs, or more, slower than the controls in reporting the colours (see Table 3).

In a fourth ANOVA, we assessed whether an object located near AE's body (i.e. within near space) but whose image appeared distantly (in the mirror, and therefore in 'far' space) was neglected less than the same object physically located far from the patient but seen directly. In other words, we compared performance in the two conditions in which the subject looked directly at the cubes held by the experimenter sitting for, who either faced or turned her back towards the patient (Conditions D and E in Figure 1), to the two conditions in which the cubes (held by the experimenter, standing near and behind his body) were observed at a distance in the mirror (Conditions G and H in Figure 1). This ANOVA included hemispace (left/right) as one within-subject factor and mirror (present/absent) as the other within-subject factor. The analysis confirmed the effect of hemispace previously described. However, the factor of mirror showed no significant effect,  $F(1, 94) = 1.05$ ,  $p < 0.30$  (mirror present: mean RT = 6.9 sec; SD = 4.4; mirror absent: mean RT = 6.3 sec; SD = 3.6). Moreover, there was no interactive effect of hemispace and mirror,  $F(1, 94) = 1.2$ ,  $p < 0.28$  (mirror present, left cube: mean RT = 8.7 sec; SD = 5.0; mirror absent, left cube: mean RT = 8.4 sec; SD = 3.6; mirror present, right cube: mean RT = 5.3 sec; SD = 2.8; mirror absent, right cube: mean RT = 4.2 sec; SD = 2.4). When the same analysis was performed separately on each control subject's RTs, there were also no significant effects of either of the factors or their interactions.

In the fifth and final analysis, we further assessed whether AE's neglect for far objects could be accounted for by the distance over which he needs to scan the environment as opposed to the physical distance of a target from his body (i.e., whether the object is either "within reach" or "out of reach"). For this analysis, we compared performance in the condition in which the subject looked directly at the cubes located near his body (Condition A in Figure 1) versus the condition in which the cubes (still located near his body) were looked at a distance in the mirror (Condition F in Figure 1). This ANOVA also included hemispace (left/right) as one within-subject factor and mirror (present/absent) as the other within-subject factor. Beside the expected effect of hemispace previously described, there was a main effect of mirror: AE was slower to name the colours of cubes located near his body but looking at them in a far located mirror (mean RT = 4.6 sec; SD = 2.4) than when looking directly at them near his body (mean RT = 3.3 sec; SD = 1.7),  $F(1, 46) = 5.4$ ,  $p < 0.02$ . The interaction effect of Mirror and Hemispace failed to achieve significance,  $F(1, 48) = 1.3$ ,  $p < 0.25$ . Again, neither control subject showed a significant effect in the same analyses for either variable or for their interaction.

## DISCUSSION

When we describe an object's position in space we often leave implicit the reference frame to which a specific location is being related. Space can be described quantitatively in different ways (cf. Shepard and Hurwitz, 1985),

namely in terms of the way space is subdivided (e.g., metric, polar), the axes of references (centred on the viewer's body and on specific parts of the viewer, e.g. the head or the eye; or centred on the object, e.g. its principal axis, on the environment), and the origin (the viewer, or another object like the north star). Space can also be described qualitatively in different ways, by use of topological descriptions or categorical spatial relations (e.g., when we use spatial prepositions to indicate in discourse an object's location, as in "the book is on the table and to the right of the telephone"; cf. Landau and Jackendoff, 1993; Laeng et al., in press). Space may also be visualized or remembered in a different way than it was originally perceived, an example of which is given by neglect patients' descriptions when asked to mentally image the main square of the city where they grew up and to report what objects they can visualize (i.e. buildings and shops; Bisiach et al., 1979). Finding impairment in neurological patients that can be best described within a specified spatial frame supports the idea that such a spatial frame is actually used by our brain. For example, the fact that some neglect symptoms are best described within an object-centred framework lends support to the idea that, at some level of processing of the visual system, an object-centred description is used (cf. Caramazza and Hillis, 1990a, 1990b).

Our study used a mirror and explored the performance of a single brain-damaged patient (AE), suffering from neglect, in reporting properties of objects shown in various locations. AE did not commit errors, but his RTs to the target objects varied in a systematic way. We interpret a change in RT as an index of a change in severity of neglect between conditions. In other words, a lengthening of responses to stimuli located in a specific region of space is taken as evidence for difficulty in directing attention towards the specific spatial region. Although this patient's diagnosis of neglect was based on omission of targets in standard clinical tests (e.g. cancellation tasks), the experimental task was performed in the same time period. It seems reasonable to conclude that AE's performance in the experiment reflected his neglect problem, given that the task required orienting to different locations.

AE neglected objects appearing in the 'far' left hemispace (taking his body position as the origin) by naming their properties (i.e. colours) more slowly than when the same objects appeared in the 'near' left hemispace. Such slow search for 'far' more than 'near' left-sided targets cannot be clearly accounted for by the patient's left-sided hemianopia, since when an object is displaced in near or far positions along the same line of perspective the resulting images would still be projected within the area of the patient's scotoma. In addition, AE was slower than controls in responding to far targets in both hemispheres. The fact that AE's RTs were slower to far than near targets in right hemispace cannot be attributed to his hemianopia, since this was left-sided. AE was in general slow in every task and such overall lengthening of RTs is common in neurological patients. Moreover, neglect for targets appearing also in right hemispace is often observed in right hemisphere patients (e.g., Weintraub and Mesulam, 1987; Duncan et al., 1999), although such ipsilesional neglect is always less severe than the contralesional.

In the light of Halligan and Marshall's (1991, 1995) interpretation of previous patients' neglect, the observed near-far dissociation could mean that the

patient neglected 'extrapersonal' space more than 'peripersonal' space. However, it remains ambiguous whether the terms 'near' and 'far' space refer to a) 'extrapersonal' and 'peripersonal' space as defined by, possibly action-based, mechanisms of attention that rely on a topological distinction based on hand movements (i.e., "reachable" versus "unreachable" space) or b) other mechanisms of attention which do not require actual contact between the object and the observer body but are based on the control of visual exploration (e.g., eye fixations). The latter system should provide a continuous differentiation of external positions; a system based on "grasping" should show abrupt changes once the maximum reaching distance is exceeded. Moreover, the same system that controls orienting of gaze, or a system similarly organized, could control action of other body parts, like the index finger, for orienting to targets in situations that do not require any contact between the observer's body parts (e.g. pointing to a distant unreachable object, such as a bird or the north star). Indeed, Cowey and colleagues (1994, 1999) found that when patients were asked to indicate the centre of a line with a hand-held laser-pointer, and when the line was shown at various distances, they were more impaired for lines further away and that there was no evidence of a sudden increase in the displacement of centre when the maximum reaching distance was exceeded (cf. Halligan and Marshall, 1991). Consistent with these considerations, a patient observed by Berti and Frassinetti (2000) neglected 'near' space more than 'far' space in a line bisection task, when a) pointing with a hand-held laser-pointer to the centre of distant lines and b) for the near lines when asked to indicate their centre either by touching it with the index finger or by pointing to it with a hand-held laser-pointer. Most importantly, when Berti and Frassinetti changed the bisection task in far space by providing the patient with a long stick and requesting him to touch the centre of the line, the patient now showed neglect in 'far' space as well. In the authors' view, the stick had become an "extension" of the patient's body, which caused a re-mapping of 'far' space as 'near' space. But the use of the stick also changed the task from one of "orienting and pointing" to one of "reaching and touching". The possibility remains that the neglect shown by their patient for both touching and pointing to the near lines could be explained by the fact that within 'near', "grasping space", pointing requires a very similar limb/hand movement toward a location within the lower region of space as for actually reaching and touching the object.

In our study, we found no evidence that AE neglected a region in "reaching-and-grasping" or "peripersonal space", since the patient neglected objects located near him, or in "reachable" positions, only when seen in a distant space (created by a mirror). Thus, AE's neglect depended on whether he had to scan the 'far' region of his left hemispace, regardless of whether the target was physically near or far. An alternative view of our findings, as well as those of Cowey and colleagues (1994, 1999), could be that this type of left hemispace neglect could increase with distance because the orientation of gaze is concomitantly required to explore a higher region of space, thus compounding the effects of "unilateral neglect" with those of "altitudinal neglect". However, this proposal will remain at this stage speculative since as yet no study has specifically addressed yet this relationship. Interestingly, a study on 100 patients with the Albert Barrage test

showed that the neglect patients' performance was worse in the lower left quadrant of the sheet (Pitzalis et al., 1997). This suggests that in neglect patients both the horizontal and vertical dimensions of space can be affected simultaneously. Hence, cancellation and bisection tasks, which require action within grasping space and, typically, actual contact between the hand and the object, could be most sensitive in revealing neglect for the lower hemispace or peripersonal space. In contrast, eye exploration tasks, like the one used in this study could be more prone to reveal a patient's neglect for 'far' space. Rizzolatti and Gallese (1988) have proposed that areas of the frontal lobes that also programme the eyes' saccades are involved in 'far' space representation. However, our patient was similar to many other neglect patients by having lesions confined to the posterior areas of the brain. Nevertheless, the possibility of "diaschisis", or long-distance effects of a subsystem on neuroanatomically 'distant' but closely connected areas, cannot be ignored.

In summary, we speculate that the dissociations between 'near' and 'far' space in neglect (or 'peripersonal' versus 'extrapersonal' space) could depend on separate action systems, one based on the control of the eyes or gaze in the exploration of space and the other based on the control of the limbs and hands in reaching for an object from a static body position. If that is the case, we would surmise that these action-based mechanisms of attention usually work together, and would orient their effectors towards the same physical location, since objects that are near and reachable would also lead eye movements towards locations that are near the viewer's body. However, the two can be dissociated, typically by use of external tools, as when viewing distant objects within a near space (e.g. in a camera surveillance system or, trivially, in your TV set) or when viewing our peripersonal space in a distant mirror.

Finally, the present study provided some support for the idea that neglect can occur simultaneously within an 'object-centred' space and a 'viewer-centred' space. AE was slowest in reporting an object held in the left hand of the investigator who turned her back towards the patient so that this hand appeared in his left hemispace. AE was better in reporting an object held in the investigator's right hand when she faced him and even faster in the other two conditions in which the cube appeared in right hemispace. To some extent AE's behaviour resembles that of the patients observed by Behrmann and Tipper (1994). After initially viewing an object (a barbell), which was then rotated slowly for 180°, patients neglected the colour of the bell that was associated to the left side of the object even in its new right hemispace location. In contrast, these same patients showed neglect exclusively for the bell in the left hemispace, regardless of presentation and rotation, when a bar did not explicitly connect the two sides of the object. Our experiment is consistent with the conclusions of Behrmann and Tipper that the left side of the object can contribute to neglect, since a cube held with the left hand in left hemispace caused a lengthening in AE's naming latencies. Our findings additionally indicate that object-centred neglect can also exist for objects that, although entirely independent from the supporting object (in this case, the human body), and do not constitute a part of it in any sense, are simply in contact with its sides. We should also note that AE's slowing for cubes held in the left hand cannot be entirely accounted for by

the need to mentally rotate the upright human figure in depth to a canonical, preferred, frontal position before reporting the cubes' colours. If so, one would have expected that both conditions in which the investigator turned her back towards the patient would have been the worst, regardless of which hand held the cubes. More importantly, although AE's performance was worse for cubes held in the experimenter's left hand when her back was turned than for cubes held in the experimenter's right hand while she faced him, when these conditions were replicated with AE now looking at the experimenter's reflection in the mirror, his performance was reversed: AE was now slowest for the "mirror, left hemispace, front-towards-AE" condition than for the "mirror, left hemispace, back-towards-AE". These findings are consistent with the patient's interpreting the image in the mirror as a true reflection of the physical object; that is, the hand in the mirror's left hemispace of a human figure who was facing him was, indeed, interpreted as this individual's actual left hand.

In conclusion, with the use of a mirror we have "thrown some light" on current ideas about different spatial reference frames and how these affect spatial neglect. In turn, this analysis of impairment in a neurological case can help us understand and refine not only our description of what a patient's problem is but also what specific reference frames may be actually used by our brain.

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