SPECIAL ISSUE

THE ROLE OF VISION IN SPATIAL REPRESENTATION

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Abstract

A complex link exists between vision and unilateral spatial neglect (USN). Firstly, USN is not a perceptual deficit, secondly, USN is not necessarily accompanied by a visual deficit and finally, USN can be observed in non-visual modalities as well as in mental spatial imagery. This apparent supramodality of USN stands in sharp contrast to the fact that neglect signs are often more severe and more durable in the visual than in other sensory modalities (Chokron et al., 2002).

The influence of vision on spatial representation has rarely been studied. In the present study we assessed six right brain-damaged patients suffering from left USN on two tasks involving spatial representations: a clock-drawing task and a drawing from memory task in two experimental conditions, with and without visual control. We confirm that even in mental imagery, the absence of visual feedback may decrease and even suppress left neglect signs (Bartolomeo and Chokron, 2001b; 2002).

Since vision is largely involved in the orientation of attention in space, suppressing visual control could reduce the magnetic attraction towards the right ipsilesional hemispace and in this way could allow a re-orientation of attention towards the left neglected hemispace. We discuss the theoretical and therapeutic implications of these findings.

Key words: vision, representation, neglect, attention

Introduction

Unilateral spatial neglect (USN) is the tendency to ignore objects in the contralesional hemispace (Bisiach and Vallar, 2000). A patient with a right parietal lobe lesion may fail to notice or respond to objects in left hemispace and may show a preference for responding to events occurring in ipsilesional space. This bias can range from a mild asymmetry of response latencies to situations in which patients seem to act as if the contralesional half of the world did not exist anymore.

Although many (but not all) neglect patients are also blind in the contralesional hemifield, this hemianopia is not the primary determinant of their behavior. Patients with hemianopia quickly learn to compensate by making more extensive eye and head movements than would normally be required (Marshall and Halligan, 1993).

More convincing evidence that USN is not strictly speaking 'visual' was provided by Bisiach and Luzzatti (1978) who first described 'representational neglect' when a patient was asked to describe a well-known place from memory. In their seminal paper, Bisiach and Luzzatti (1978) reported two left neglect patients who, when asked to imagine and describe from memory the Piazza del Duomo in Milan, omitted to mention the left-sided details regardless of the imaginary vantage point that they assumed, thus showing representational or imaginal neglect. This finding was replicated by Bisiach et al. (1981) in 28 neglect patients and the authors proposed that neglect patients suffer from "a representational map reduced to one half" (Bisiach et al., 1981; p. 549).

The tasks used to assess representational neglect include: describing familiar places from memory, naming the towns or the countries on a map from memory, and drawing objects from memory. In the traditional clock drawing test, a patient presenting with left representational neglect is likely to produce clock drawings with the left half missing. Nevertheless, as pointed out by Vallar and colleagues (1991, p. 230) 'if the basic deficit underlying spatial neglect concerns the inner representation of extrapersonal space, the prediction can be made that sensory parameters, such as the availability of visual cues, should not influence the manifestation of the deficit, in terms for instance, of its severity'. Contrary to this claim, Anderson (1993) described a patient with stroke induced damage to the right parietal lobe and to the right thalamus who reliably produced clock drawings with the left half missing when tested, as is customary, with the eyes open. However, when required to perform the same task with eyes closed, her clock face was drawn normally with all 12 numbers appropriately placed around the full circumference (Anderson, 1993, p. 215). To explain this finding, Anderson argued that "right-sided external percepts are more 'sticky' than internal images" (Anderson, 1993, p. 215). In the same way, Marshall and Halligan (1993) described the case of JR, a left neglect patient, whose performance in geometric shape drawing and in letter cancellation was always better when performed with eyes closed rather than eyes open. In fact, Chedru (1976) was the first to mention, some thirty years ago, the negative effect of vision on the severity of left neglect signs and subsequently Mesulam (1985) and

TABLE I
Demographical and clinical data, and performance on the neglect battery

Patient	Gender / age / Days from onset	Aetiology	Locus of lesion	Visual deficit	Left extinction	Line bisection (% deviation)	Bells cancellation (max 15/15)	Overlapping figures (max 10/10)	Landscape drawing (max 6)
Patient N. 1	F / 81 / 252	Hemorrhagic	TO	LH	no	+ 5.5	0 / 10	4 / 10	4
Patient N. 2	F / 57 / 728	Hemorrhagic	T	LIQ	no	– 13.15	0 / 8	6 / 10	4.5
Patient N. 3	M / 56 / 21	Hemorrhagic	PO	LH	yes	+ 15.3	4 / 11	6 / 10	5
Patient N. 4	M / 63 / 57	Ischemic	TP	LH	no	+ 27.8	8 / 13	7 / 10	4.5
Patient N. 5	M / 64 / 196	Ischemic	PO	LH	yes	+ 21.8	6 / 14	7 / 10	–
Patient N. 6	M / 58 / 63	Ischemic	PO	LH	no	+ 52.90	10 / 9	10 / 10	4
Controls (n = 14)	F: n = 7 / M: n = 7								
Mean age:	47,5 (sd = 14.2)								

Gender: F: female M: male
Lesions: F: frontal, T: temporal, P: parietal, O: occipital
Visual deficit: LH: left hemianopia; LIQ: left inferior quadrant anopia
–: Missing data.
For line bisection, + indicates rightward deviation and – indicates leftward deviation.
For the Bells cancellation test, left / right correct responses are reported.
For overlapping figures, the number of correct responses on the left and on the right is reported.
The landscape drawing, consisting of a central house with two trees on each side, was scored by assigning 2 points to the house and 1 point to each tree completely copied.

Anderson (1993) replicated this finding in clock drawings. These are the first observations that visual feedback may exacerbate left neglect in right-brain-damaged (RBD) patients.

Investigating why left neglect patients omit to draw or copy the left side of objects and why they do not notice that the left side is missing even when their drawing remains in free view, Halligan and Marshall (1994) asked left neglect patient PB to copy a butterfly in various conditions. PB had first to copy a regular butterfly, then a butterfly with the left or a right half missing. In a second session, he was requested to draw from memory his copy with eyes open and with eyes closed. Finally in a third session he was asked to draw from memory with eyes open a butterfly with its body vertically aligned, then the same butterfly, but rotated through 90°, and again in the usual vertical body orientation as previously. PB drew a butterfly with two wings only in two conditions: when drawing butterflies with his eyes closed, and when drawing a horizontally-oriented butterfly (one wing above the other on the picture plane) with his eyes open. Although all PB's other butterflies were missing a left wing, PB was insistent that he had drawn a full butterfly. In their paper, Halligan and Marshall (1994) discussed the possibility of a completion phenomenon in neglect preventing the patients from noticing their omissions on the left side. Given the possibility of an interaction between partial perceptual information and preserved conceptual knowledge (revealed by the eyes closed performance) these patients would not experience life in a 'half-world'.

Taken together, the above findings raise the question of the role of visual feedback and visual context on the representation of space in USN patients. It should be noted that in the vast majority of studies dealing with representational neglect, there is no mention of how vision was controlled during the task, nor even any mention of whether the patient performed the task with eyes open or closed. The aim of the present study was therefore to investigate the influences of vision and more precisely of visual feedback on spatial representations in RBD patients suffering from left USN. In the first experiment, we had patients draw clocks in order to replicate Anderson's findings (Anderson, 1993); in the second experiment, patients were asked to draw symmetric or asymmetric objects. These two experimental tasks were performed by all control subjects and neglect patients with eyes open and with eyes closed.

Experiment 1: Clock-Drawing Test

Methods

Subjects

Fourteen normal control subjects (7 men, 7 women) aged between 28 and 75 years (mean: 47.5 years, sd = 14.2) were assessed. All were right-handed according to the questionnaire of Dellatolas et al. (1988).

Six right brain-damaged patients (2 women, 4 men) suffering from severe left unilateral spatial neglect after a stroke were assessed. Neglect signs were evaluated with the Batterie d'Evaluation de la Négligence (BEN: Azouvi et al., 2002; Rousseaux et al., 2002). Subjects' clinical and demographical data are presented in Table I. Performance on the neglect battery is also shown.

Procedure

Subjects were seated in front of a large table. Their trunk and head were aligned at 0°, with the sagittal midplane corresponding to the objective center of the table. Although all patients could sit by themselves and perform the task, trunk and head positions were carefully monitored by the experimenter throughout the task.

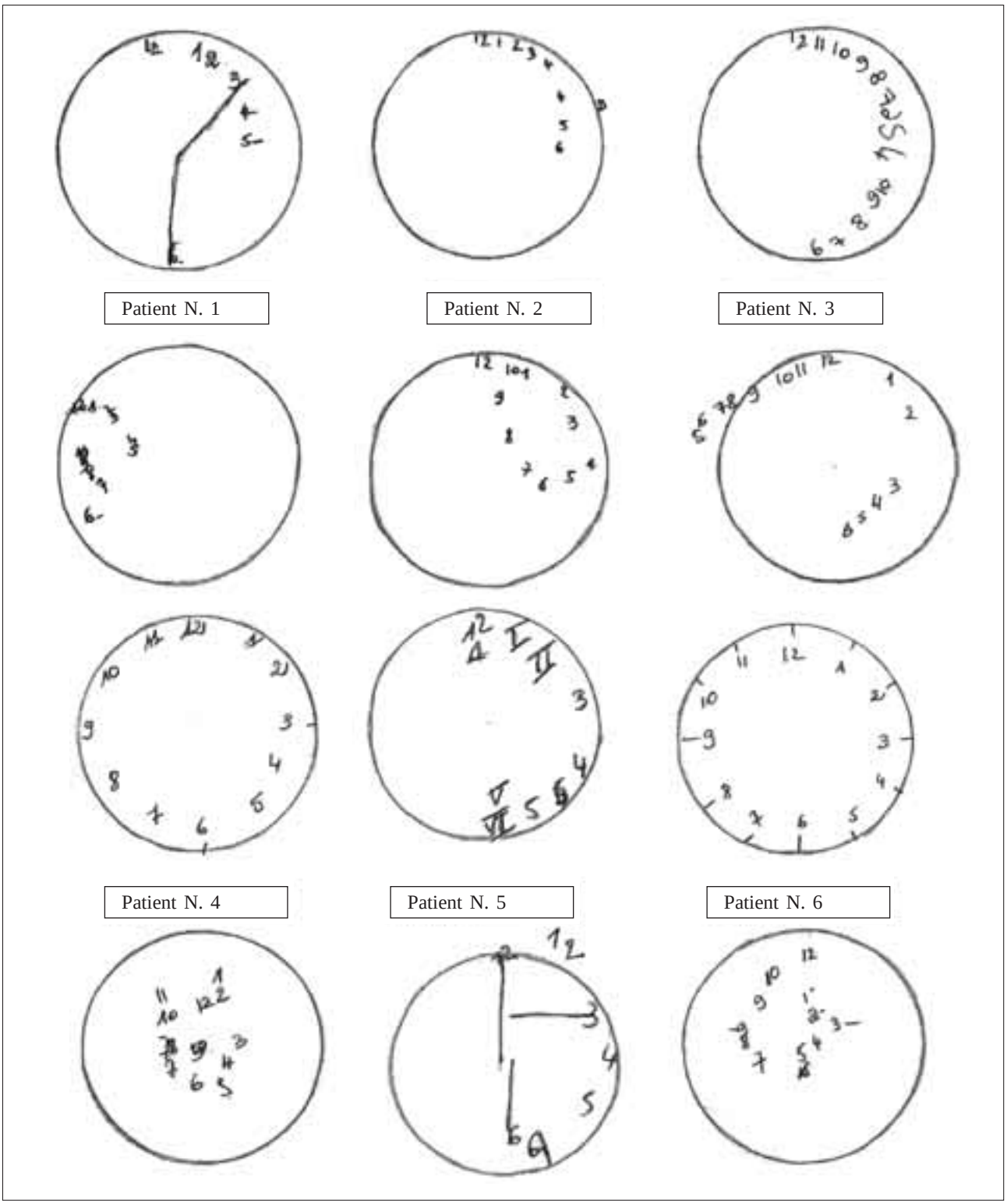

Fig. 1 – *Clock drawings in the eyes open condition (top) and eyes closed condition (bottom) for the six left neglect patients.*

Participants were asked to complete a clock dial drawing with their right dominant hand with eyes closed and eyes open. Half of the subjects began with the eyes closed condition, whereas the remaining half proceeded in the reverse order. In each condition, the subject's hand was initially positioned on the sheet of paper at a point corresponding to the centre of the page and to the centre of the clock.

Results

Control Subjects

No omission was recorded in either experimental condition (eyes open or eyes closed) and the clock drawings were fully complete.

Neglect Patients

Figure 1 clearly shows that for patients N. 1, N. 2

and N. 3 the left neglect was obvious in the eyes open condition (left half or numbers from 6 to 12 missing), whereas the eyes closed condition dramatically reduced the signs of left neglect (all numbers were present). For patient 5, the left neglect was not affected by the visual condition, but the digital numbers were more coherent in the eyes closed condition (Figure 1).

For two out of six patients (patients N. 4 and N. 6) the clock dial was correctly completed independent of the visual condition (Figure 1).

Discussion

The main finding of the first experiment was that in three out of six patients, the clock drawing showed less neglect in the eyes closed condition compared to the eyes open condition. In the three remaining patients, the visual condition had no effect on the patients' performance which was at ceiling in both conditions (patients N. 4 and N. 6). Only for patient N. 5 was the neglect stable in the two conditions. These results confirm Anderson's findings in showing that visual guidance may increase left neglect in clock drawing in some patients. According to Anderson (1993), "right-sided external percepts are more 'sticky' than internal images". Along these lines, eliminating visual control would thus improve the results by eliminating the "magnetic attraction" (see Gainotti et al., 1991) to extraneous visual stimuli in the right hemispace. This hypothesis is consistent with the results of Mark et al. (1988) who tested left neglect patients in a line cancellation task where the targets may be either drawn over or erased. Patients made more omissions in the task where they cancelled with visible marks than in the erasing task, as if they were suffering from both a primary attraction to the right hemispace and from an inability to disengage attention from the right hemispace in order to re-orient it to the left one (Posner et al., 1984). This hypothesis was also proposed by Di Pellegrino (1995), who tested a patient (CB) with severe left visuo-spatial neglect and hemianopia after right hemisphere stroke on three conditions of a clock-drawing task. Both on spontaneous drawing and when the number sequence was provided by the experimenter, CB drew a clock face with left-sided numbers transposed to the right side of the dial; in contrast, when each number was drawn on a separate dial, its location was correct and there was no transposition. Whereas directional hypokinesia or a representational deficit cannot explain these effects, the author proposed that a deficit in disengaging attention from right-sided visual stimuli could play a critical role in clock drawing performance.

Experiment 2 was designed to test this hypothesis in a task where neglect patients were asked to draw objects from memory. As in Experiment 1, the eyes closed condition may, compared to the eyes open condition, reduce left neglect signs in some neglect patients by decreasing the magnetic attraction toward right-sided details when drawing objects from memory.

Experiment 2: Drawing Objects from Memory

Methods

Subjects

The same subjects examined in Experiment 1 were tested.

Procedure

Subjects were asked to draw 16 objects from memory:

– 8 symmetric objects:

– 4 manipulable objects (pair of goggles, pair of trousers, earphones, pullover);

– 4 non-manipulable objects (butterfly, heart, spider, bench);

– 8 asymmetric objects (with a front and a back end)

– 4 manipulable objects (cup, saucepan, toothbrush, saw);

– 4 non-manipulable objects: 2 static: (cap, flag); 2 mobile: (truck, child's scooter);

Each participant drew the objects in a specific randomized order, on a sheet of paper (14.8 cm $\times$ 10 cm) with a black pen. For half of the participants, the task was first performed eyes open and then eyes closed, whereas the remaining half performed the task in the reverse order. There was no time limit.

Data Analysis

Several dependent variables were recorded for each visual condition. Our aim was not to conduct a statistical analysis on these data (there were only 16 drawings per subject) but rather to analyse descriptively the drawings with respect to characteristics such as the drawing's completeness, the symmetry of the drawing, the respective left and right surfaces and the lateralisation of the details.

Drawing completeness: 5 independent judges were requested to decide if the drawing was complete or not. A complete drawing was coded +1 whereas 0 referred to an incomplete drawing.

Drawing symmetry: for symmetrical objects, we recorded the presence or absence of items on each side of the axis of symmetry of the object. The drawing was coded +1 if the left and the right part were symmetric and 0 if they were asymmetric.

Left and right surfaces: Figure 2 illustrates how the left and right surfaces of the drawing were calculated.

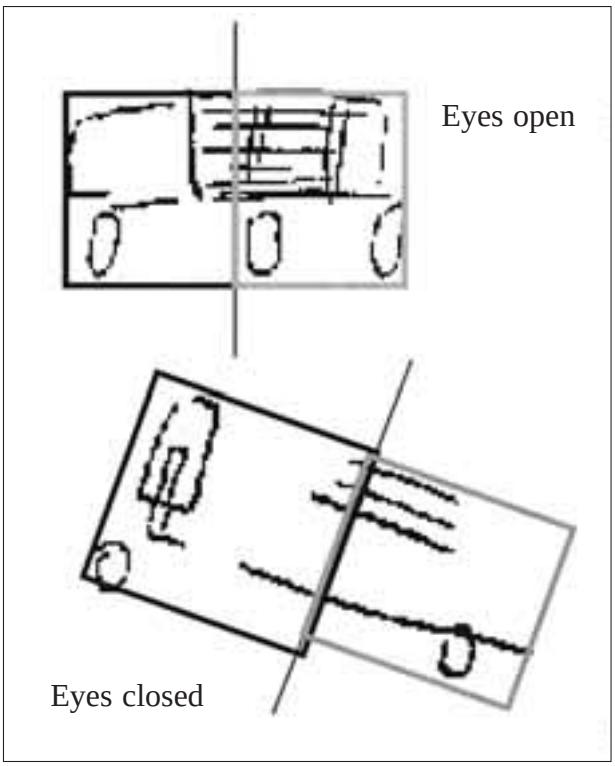

Fig. 2 – *Calculation of the left and right surfaces of the drawing.*

When the left half surface was bigger than the right half, the drawing was coded – 1, when the right half surface was bigger than the left half it was coded + 1, and 0 corresponded to a drawing where the two surfaces were equal.

Lateralisation details: we recorded the drawing half (left or right) that included the greater number of details.

Results

Drawing Completeness

Table II shows the drawing completeness when control subjects and neglect patients performed with eyes closed and eyes open.

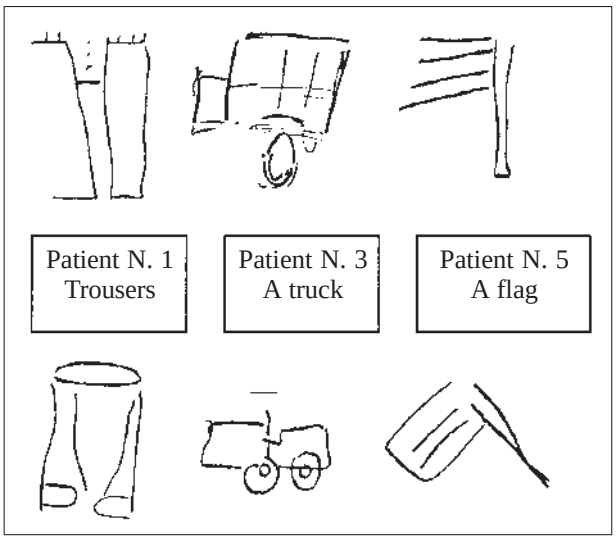

Fig. 3 – *Drawing trousers, a truck, a flag in the eyes open (top) and eyes closed conditions (bottom) for patients #1, #3 and #5. These examples illustrate how in these patients the suppression of visual guidance (bottom) may improve the completeness of the drawings.*

In controls, the visual condition had no effect and in all conditions, the object drawn was complete.

By contrast, in some neglect patients, performance was affected by condition. When condition had a positive influence on the performance of neglect patients, it was always in favour of the eyes closed condition.

As shown in Figure 3, in patients N. 1, N. 3 and N. 5, the eyes closed condition led to more complete drawings than the eyes open condition.

For patients N. 2, N. 4 and N. 6, condition had no effect on drawing completeness because it was almost perfect in both conditions (see Table II).

Figure 4 illustrates how in patients N. 3 and N. 5, suppression of visual feedback may improve the completeness of drawings, making them more recognizable.

Symmetry of the drawing

Again, in normal controls, condition did not affect the symmetry of the drawing (Table II).

TABLE II

Completeness of the drawing, symmetry, surface and lateralisation of the details for symmetric (SO) and asymmetric objects (AO) in the eyes open (EO) and eyes closed (EC) conditions, for neglect patients and controls

	Completeness				Symmetry		Surfaces				Lateralisation details			
	EO	EC	EO	EC	EO	EC	EO	EC	EO	EC	EO	EC	EO	EC
	SO	SO	AO	AO	SO	SO	SO	SO	AO	AO	SO	SO	AO	AO
P1	0.5	0.625	0.5	0.875	0.625	0.65	0.25	– 0.5	0	– 0.125	0	– 0,125	0	0
P2	1	1	0.875	0.875	1	1	0.25	– 0.25	0	0	0.125	0	0	0
P3	0.75	0.875	0.5	0.875	1	1	0.5	– 0.375	0.25	0	0.375	– 0.125	0.5	0
P4	0.875	0.875	0.875	0.875	0.825	0.88	0.75	0.25	0	– 0.125	0.25	– 0.125	0.25	– 0.125
P5	0.5	0.625	0.75	0.75	0.825	0.94	0.25	0.125	0.125	0	0.125	0	0.125	0
P6	1	1	1	1	1	1	0	– 0.25	0	0	0	0	0	0
Controls	0.98	0.955	1	1	1	1	– 0.053	0.071	0	0.018	0.026	0.035	0.019	0.022

Completeness: 1 = complete; 0 = incomplete
Symmetry: 1 = symmetric; 0 = asymmetric
Left and right surfaces: – 1: left surface > right surface; + 1: right surface > left surface; 0: left surface = right surface
Lateralisation of the details: – 1: more details in the left half; + 1: more details in the right half; 0: left details = right details

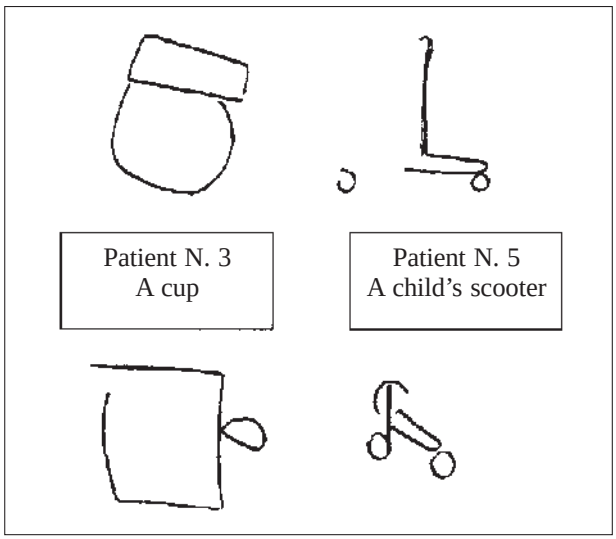

Fig. 4 – *Examples of drawing a cup, a child's scooter in the eyes open (top) and eyes closed conditions (bottom) for patients #3 and #5, illustrating how the increased completeness in the eyes closed condition make the drawings more recognizable.*

For patients N. 2, N. 3 and N. 6, the symmetry of the drawing was respected independent of condition (see Table II). In contrast, for patients N. 1, N. 4 and N. 5, the drawing symmetry improved in the eyes closed condition compared to the eyes open condition as shown in Figure 5.

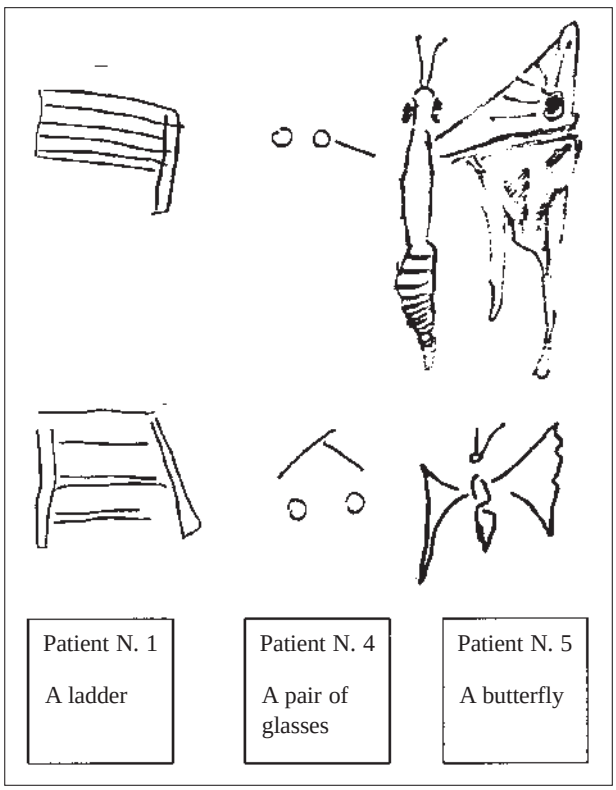

Fig. 5 – *Examples of drawing a ladder, a pair of glasses, a butterfly in the eyes open (top) and eyes closed conditions (bottom) for patients #1, #4 and #5, showing how the eyes closed condition may improve the symmetry either by drawing the left part (neglected with eyes open) or by reducing the size and number of details on the right part (too detailed in the eyes open condition for patient #5).*

Drawing Surface

In controls, performance did not depend on conditions: left and right surfaces were comparable (see Table II).

In all neglect patients, the condition influenced the left and right drawing surfaces mainly for symmetric objects (see Table II).

In patients N. 1, N. 2, N. 3 and N. 6, when drawing symmetric objects, the suppression of visual control increased the surface of the left half or decreased the surface of the right half of the drawing compared to the eyes open condition (see Table II, Figures 6, 7).

In patient N. 4, the right surface was always bigger than the left one, but this discrepancy was reduced when the patient drew with his eyes closed (see Table II).

In patient N. 6, the left and right surfaces were comparable except in the condition where the patient drew symmetric objects with his eyes closed. In this condition, the left surface was bigger compared to the right one (see Table II: a negative score with EC means that the left surface is bigger than the right one).

Lateralisation Details

For control subjects, the visual condition did not affect the distribution of the details in each half (left and right) of the drawings (see Table II).

Conversely, as shown in Table II, in all neglect patients except patient N. 6, the eyes closed condition led to less asymmetric (or more symmetric) drawings than the eyes open condition, either by decreasing the details on the right side (patients N. 3, N. 4 and N. 5) or increasing the

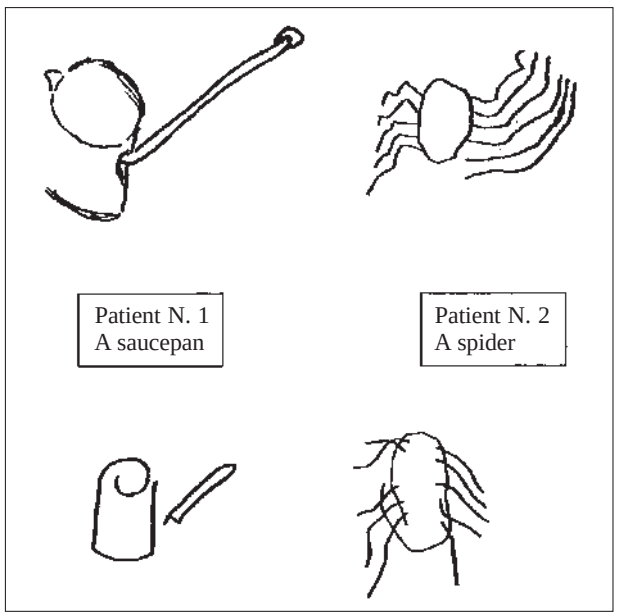

Fig. 6 – *Examples of asymmetry between the left and right surfaces when drawing a saucepan, a spider in the eyes open condition (top) for patients #1 and #2 that was reduced in the eyes closed condition (bottom).*

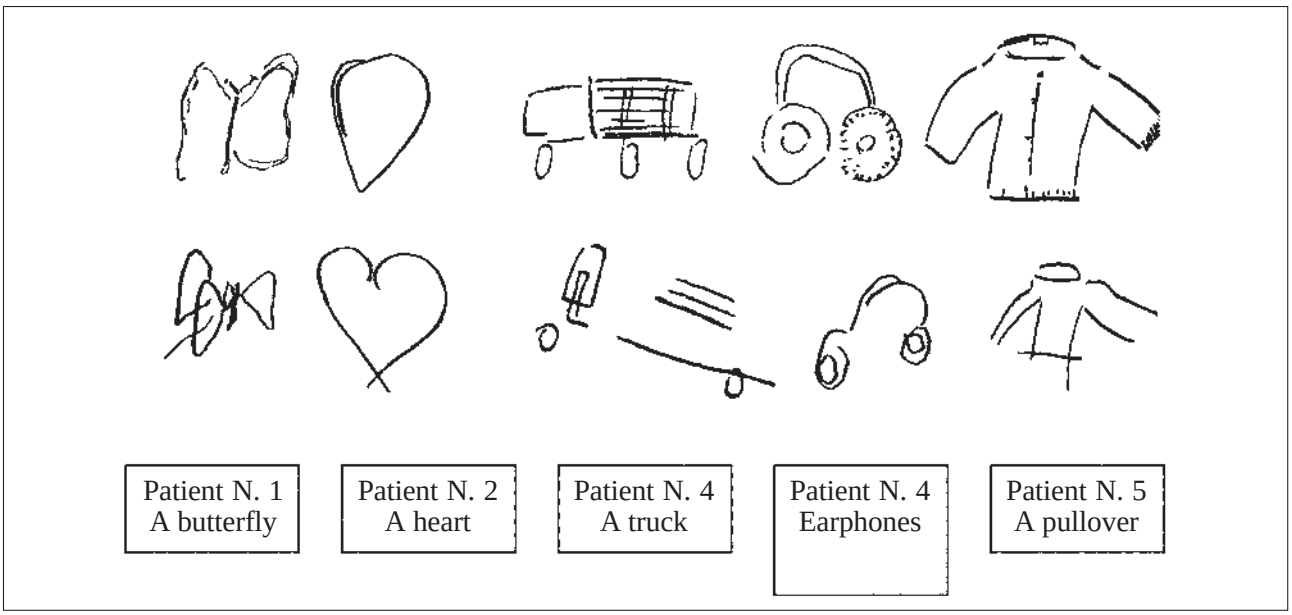

Fig. 7 – *Examples of rightward lateralisation of details in drawing a butterfly, a heart, a truck, earphones, a pullover in patients N. 1, N. 2, N. 4 and N. 5 in the eyes open condition (top) that shifted to the left side (patient N. 1, N. 2), and/or decreased on the right side (patient N. 4, N. 5) in the eyes closed condition (bottom).*

details on the left side (N. 1, N. 2 and N. 3). This is illustrated in Figure 7, which also shows that in the eyes closed condition the number of details on the left side can dramatically increases as in patient #1 who drew with eyes open a butterfly with an incomplete left wing and with eyes closed a butterfly with two left wings!

Discussion

The main finding of Experiment 2 is that whereas the presence or absence of visual feedback never influenced the performance of normal subjects, all neglect patients were at some point sensitive to it. In addition, when the condition had an affect on their drawing, it was always in the same way, that is, a decrease of left neglect signs when visual feedback was suppressed. Interestingly, the improvement could result from either a decrease of the right half surface and a reduction of the details drawn in the right half, and/or from an increase of the left half surface of the drawing and more details drawn in the left part. These findings indicate that left neglect patients may be hyperattentive to right hemispace. This bias could be due to an inability to disengage attention from the right hemispace (Posner et al., 1984) or to a rightward shift of attention as predicted by Kinsbourne's hypothesis (1970a; 1970b). In accordance with Experiment 1 and previous findings (Halligan and Marshall, 1994), drawing with one's eyes closed may improve the performance of left neglect patients by inducing a disengagement from the right half of the drawing and a re-orientation of attention to the left half of the drawing. This hypothesis was also put forward by Hjaltason and Tegner (1992) to explain why darkness improved line bisection by about 43% in left neglect patients. According to the authors, the improved performance may have been due to the elimination of extraneous visual stimuli from right hemispace.

Taken together, these findings suggest that under visual control, attentional resources are captured and maintained in the right hemispace, thus increasing left neglect behaviour. Eliminating visual control thus improves performance by eliminating the magnetic attraction to extraneous visual stimuli from right hemispace.

General Discussion

The main finding of this study is that suppressing visual control may improve left neglect patients' performance in a clock drawing task and in drawing objects from memory. Whereas control subjects draw objects in the same manner whether their eyes are open or closed, neglect patients draw more complete and symmetric drawings in the eyes closed compared to the eyes open condition. These findings confirm and extend previous studies.

Chedru (1976) designed a test suitable for presentation in equivalent tactile and visual versions: subjects were required, with and without a blindfold, to tap the keys all over a teletype keyboard as quickly as possible. RBD patients with visual field defects showed no impairment in tapping the left-sided keys when vision was obscured, while they preferred the right-sided keys when visual control was available. Chedru's conclusion (1976) was that the unilateral defect in manual exploration of space is induced by vision. Using the same protocol, Gentilini et al. (1989)

reported that RBD patients with neglect preferred the right-sided keys, both with and without visual control, although this ipsilateral preference was significantly less marked in the tactile condition. Gentilini et al. (1989) have tested space exploration among RBD patients with and without visual control (blindfolded condition) with a modified version of Chedru's test (pressing the keys of a keyboard). They found that in left neglect patients the ipsilesional preference was significantly less marked in the blindfolded condition, than when performance was assisted by vision. This kind of dissociation was replicated by several authors during space exploration tasks (Cubelli et al., 1991; Ladavas et al., 1993). In the same way, Vallar et al. (1991) submitted 110 unilateral brain-damaged patients to a spatial exploratory task with and without the aid of vision. Like Chedru (1976), the authors reported an association between the modal specificity of the deficit and the presence/absence of visual field impairments. Neglect confined to the visual condition was associated with left homonymous hemianopia or extinction, while about 70% of the patients with neglect in the tactile condition did not show visual field deficits. These findings were interpreted as reflecting the presence of nonsensory (attentional or representational) components in the visual field defects of neglect patients.

Using bisection protocols, Hjaltason and Tegner (1993) found that a rod bisection task performed by left neglect patients while blindfolded elicited less rightward bias than visual line bisection. This discrepancy between visual and tactile conditions may not be due to different spatial search mechanisms (visual or haptic) but can be explained solely by the presence or absence of visual information, as in the present study or in Hjaltason and Tegner (1992), where the line bisection task performed in darkness elicited less rightward bias than in normal illumination. However, it has to be noted that, when submitting left neglect patients to a line bisection task either in a supine or in an upright position in light or dark conditions, Pizzamiglio et al. (1997) did not find any significant effect of illumination. Only a mild tendency toward reduced error in bisecting a line in the dark condition was reported.

Concerning auditory neglect, it has been shown that blindfolding improves the ability of neglect patients to localize correctly sound stimuli originating from the left (Soroker et al., 1997). This suggests that vision, including head turning and eyeball movement, may exacerbate neglect signs in various sensory modalities as well as in mental imagery, as the present findings (Figures 1-7) demonstrate. According to Gentilini et al. (1989), the increase in ipsilateral responses when key pressing was guided by vision in comparison to the blindfolded condition suggests that incoming sensory stimuli from the ipsilateral side play a role in shifting attention towards it and in enhancing neglect of the contralateral side of space. In fact, although several experiments have shown that attention can be allocated to different parts of the spatial field without overt eye movements (see Posner, 1980), experiments performed in healthy subjects have suggested that eye movements cannot be made without shifting the focus of attention in the same direction (see Gainotti, 1993).

If neglect behavior results not only from hypoattention to contralateral stimuli but also from hyperattention to ipsilateral stimuli (Kinsbourne, 1970; Bartolomeo and Chokron, 1999a; 2001b), it is conceivable that a task carried out in the absence of visual stimulation, such as the tactile test, or drawing while blindfolded as in the present study, entails a less marked imbalance between the two halves of space than the same task carried out with visual assistance. Drawing a clock or objects from memory are tasks that require access to and exploration of visuo-spatial representations. The present results clearly show that the conditions, with or without visual feedback, may affect neglect patients' performance during a nonvisual, representational task.

As Bisiach and co-workers have demonstrated in their seminal papers, neglect can occur not only in vision, but also in the absence of any physical object in the patient's visual field (Bisiach and Luzzatti, 1978; Bisiach et al., 1981). In these studies, imaginal neglect co-occurred with visual neglect. This association has often been interpreted as supporting pictorial models of visual mental imagery (Bisiach et al., 1990; Kosslyn, 1994). Neglect patients avoid mentioning left-sided imagined details because they lack the left half of a (spatially organized) mental representation (Bisiach and Luzzatti, 1978). However, the accumulation of neuropsychological evidence of multiple dissociations between imagery and perceptual abilities in brain-damaged patients (recently reviewed in Bartolomeo, 2002), has proved devastating for models of mental imagery based on a functional and anatomical equivalence between these abilities, like Kosslyn's pictorial model (Kosslyn, 1994, see also Bartolomeo and Chokron, 2001b; 2002). However, as confirmed by the present findings, there is a strong link between vision and spatial representation.

To explore the relationships between visual and imaginal neglect, Bartolomeo et al. (1994) assessed 30 right- and 30 left-brain-damaged patients, and found imaginal neglect only in right brain-damaged patients. Imaginal neglect always co-occurred with visual neglect, and scores measuring the lateral bias in the two types of tasks were positively correlated, thus suggesting that the two disorders share some common underlying mechanism. In fact, about two thirds of left neglect patients showed definite signs of neglect only in visual tasks, and not in imaginal tasks, probably because

right-sided visual details exerted a powerful attraction on patients' attention (Gainotti et al., 1991). However, when imaginal neflect was present, it was always associated with visual neglect. Additional evidence confirming a relationship between visual and imaginal neglect comes from the outcome of manoeuvres known to modulate visual neglect. When a patient had his eyes and head physically turned toward the left side, his descriptions from memory included more left-sided details (Meador et al., 1987). Similar results were obtained by irrigating patients' left ears with cold water (Rode and Perenin, 1994), a vestibular stimulation likely to induce a leftward orientation of attention (Gainotti, 1993). Imaginal neglect was also reduced by a short adaptation period to a prismatic rightward shift of the visual field (Rode et al., 2001), another manoeuvre known to ameliorate visual neglect (Rossetti et al., 1998). Thus, sensory-motor procedures can influence imaginal neglect. Conversely, a purely imaginal training can ameliorate visual neglect (Smania et al., 1997). It has been proposed that at least some of these procedures act by facilitating leftward orientation of attention (Gainotti, 1993; Chokron and Bartolomeo, 1999; Bartolomeo and Chokron, 1999b). The present findings support the hypothesis that orienting attention through visual control can influence space-related imagery. Visual imagery may thus involve some of the attentional exploratory mechanisms that are employed in visual behaviour. For this reason, we think that investigations of representational neglect should include two distinct testing conditions: with and without visual guidance. In some cases, the suppression of visual guidance will dramatically reduce what looks like representational neglect.

The present study has some important implications not only for the diagnosis of representational neglect but also for rehabilitation. As mentioned above, it has already been shown that representational training may improve visuo-spatial neglect (Rode et al., 1996; Smania et al., 1997). In the present study**,** we show that suppressing visual input may improve left neglect during representational spatial tasks. These findings resemble previous neurophysiological studies on rodents. Vargo et al. (1998; 1999) showed that 48 hours of light deprivation after unilateral traumatic contusion injury to the frontal cortex significantly accelerated recovery from attentional (neglect) but not sensori-motor deficits. This improvement persisted long after the animal had been placed back under standard light cycles. These findings suggest that there may be a short, early window during which environmental variables promote or deter long term recovery. According to Vargo et al., light deprivation should improve recovery after traumatic contusive brain injury by enhancing dopaminergic function in the ipsilateral basal ganglia.

The present experiments show that in humans, light deprivation may lead to a reduction of neglect during representational tasks. Rehabilitation techniques should perhaps incorporate visuo-spatial training while blindfolded at the acute stage. Regarding normal spatial cognition, the amount and type of available visual information may also, as we have previously shown, influence how extrapersonal space is represented and/or explored (Chokron et al., 1997; Chokron and De Agostini, 2000; Chokron et al., 2002). The interaction between vision, attention and representation should accordingly be more thoroughly studied.

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