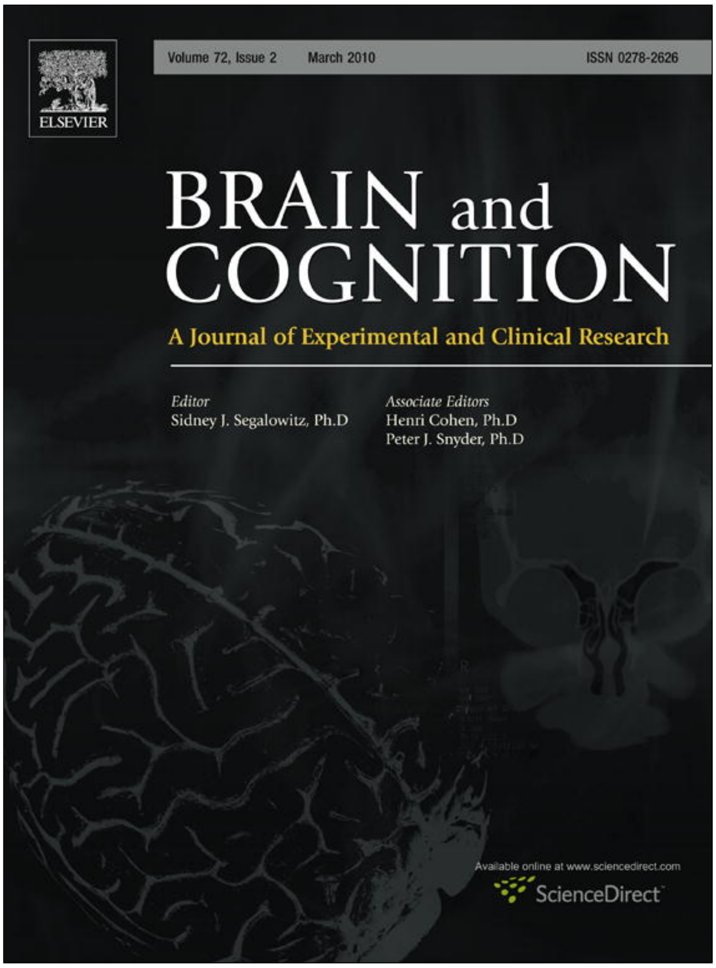
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"Where is the sun" for hemi-neglect patients?

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ABSTRACT

Human observers use prior constraints to disambiguate a scene; in particular, light is preferentially seen as coming from above but also slightly from the left. One explanation of this lateral bias could be a cerebral hemispheric difference. The aim of the present study was to determine the preferred light source position for neglect patients. For this purpose, we used the ambiguous shaded "Polo Mint" stimulus, a ring divided into eight equal sectors. All sectors but one were the same shape, convex or concave, as determined by the light source position. Participants had to report the side (left or right) of the odd sector or, in a separate experiment, to report its shape (convex or concave). Eight patients with spatial neglect (left neglect $N = 7$, right neglect $N = 1$) after a right or left temporo-parietal or thalamic lesion and 14 control participants ran the experiment. Left neglect patients showed a significantly different light bias from the bias observed for controls and for the right neglect patient (i.e., a reduction of the left bias or a right bias rather than a left bias). We conclude that some disabilities presented by patients with spatial neglect may be due to difficulties processing information that is not present in the visual field or imagined in the representational scene.

1. Introduction

Our subjective experience of a visual scene is usually stable, robust and unitary in spite of the fact that our retinal image is consistent with an infinity of three-dimensional (3D) scenes. The choice of a particular scene is the result of several assumptions made by the visual system. Several cues in an image enable us to assess the 3D structure of our environment. For instance, the depth, orientation, and shape of surfaces can be computed from the disparities between the two eyes, the relative motion of object features or the patterns of shading. In particular, the ability to identify shadows is critical to the correct interpretation of a visual scene. Related to the appropriate use of the shadow cue is the assumption that light comes from above our heads (Ramachandran, 1988). Thus, a visual scene representation is based on cues, both those that are present in the scene and those that are not.

Shading refers to the reflected light from a surface that varies according to its shape and is thus a potentially important source of information about the object. Cast shadows (those occluded surface parts that are remote from the occluding object) are critical for the perception of spatial layout (Kersten, Knill, Mamassian, & Bülthoff, 1996). In order to identify object surfaces, the visual system must locate the borders that make up an object and those that distinguish it from surrounding objects. In a natural scene with multiple objects, the visual system has to solve the "shadow correspondence problem" to explain the presence of dark patches in the image (Mamassian, 2004) and to distinguish between shadows and paint (Freeman & Viola, 1997).

Surprisingly, the preferred assumption also appears to be that light comes slightly from the left rather than directly from above. In a visual search paradigm, Sun and Perona (1998) have shown that observers discriminate convex from concave hemispheres at different speeds depending on the light source position. Response times were significantly shorter when the light source was located above and to the left.

In a recent study, Gerardin, de Montalembert, and Mamassian (2007) used a new shaded stimulus, called the "Polo Mint." The Polo Mint stimulus corresponds to a ring divided into eight equal sectors; all of them have the same form (convex or concave) except for one (when the stimulus is concave, the sector is convex and vice versa). This study clearly demonstrated that lighting an object from the left improves the ability to extract the shape of that object. Another finding was that observers without neurological damage had a bias to perceive the stimulus as a convex ring with a concave hole in it.

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The results of that study suggest that the assumed light source position not only modulates the perceived shape of an object but also the accuracy with which this shape is perceived. The bias for the left is difficult to explain ecologically because observers are very often exposed to illumination from the right as well as the left, as well as multiple sources of illumination (secondary reflections, diffuse illumination). While it is true that humans are rarely directly underneath the sun, it would be difficult to prove that they orient themselves considerably more often with its light on their left side. Even if this were the case, in Mamassian and Goutcher's (2001) view, "it remains to be shown that this body orientations bias is sufficient to induce the perceptual bias reported (here)" (p. B7).

Rather than an environmental bias affecting the position of the light source, a hemispheric difference in processing shading information could explain the results. We can, for instance, envisage that left light source positions are represented in the right hemisphere, and reversely for right light source positions.

In this study, we wished to evaluate how patients suffering from spatial neglect process assumptions about the light source position in a visual task.

Unilateral spatial neglect refers to a failure to report, respond, or orient to stimuli presented to the side contralateral to the affected brain hemisphere (Heilman, Watson, & Valenstein, 2003). Spatial neglect is observed following damage to various cortical regions including the parietal, temporal and frontal lobe (Karnath, Berger, Küver, & Rorden, 2004; Mesulam, 1999; Mort et al., 2003) or subsequent to subcortical lesions such as damage to the thalamus, putamen or globus pallidus (Karnath, Himmelbach, & Rorden, 2002; Karnath et al., 2004).

Spatial neglect selectively affects different reference frames and regions of space such as personal, peripersonal and extra-personal space (Buxbaum, 2006; Halligan, Fink, Marshall, & Vallar, 2003; Laeng, Brennen, Johannessen, Holmen, & Elvestad, 2002). Furthermore, patients sometimes neglect the left side of visual objects (object-based neglect) irrespective of their location in space (Driver & Mattingley, 1998). Spatial neglect may affect different cognitive processes in isolation, such as reading (Paterson & Wilson, 1990; Riddoch, 1990; Warrington, 1991) or writing (Auclair, Siéroff, & Kocer, 2008; Cubelli, Guiducci, & Consolmagno, 2000). These varying symptoms and their multiple associations within individual patients make it difficult to develop conclusive neurocognitive models of this spatial disorder (see Kerkhoff (2001), for a review of neglect models based on the ideas of distorted reference frames or impaired motor control). Indeed, several models have been proposed to explain neglect as resulting from a motor deficit (e.g., Bisiach et al., 1995; Ghika, Ghika-Schmid, & Bogousslavsky, 1998), an attentional orienting deficit (e.g., Kinsbourne, 1993; Mesulam, 1998; Siéroff, Decaix, Chokron, & Bartolomeo, 2007), a representation deficit (e.g., Bartolomeo & Chokron, 2002; Bisiach & Luzzatti, 1978; Rizzolatti, Fadiga, Fogassi, & Gallese, 1997), or a spatial working memory deficit (Cristinzio et al., 2009; Malhotra et al., 2005). Consequently, there is no consensus about the causal mechanisms of spatial neglect.

The aim of the present study was to evaluate how neglect patients treat information that is not present in the visual scene or not imagined in the representative scene. More specifically, it was to evaluate how patients suffering from spatial neglect infer the position of the light source in a visual shape discrimination task. Many tasks are used to assess spatial neglect, such as cancellation, copying a figure, drawing objects from memory, and describing places from memory. Each of them can reveal different aspects of neglect, but some tests appear to be less sensitive than others. Dissociations of performance on these tests have been described and different interpretations have been proposed. One important point is that these tests are built based on the same paradigm: a stimulus or a representation whose consequences are visible. However, the representation of space implies other factors, some of which are not visible; using non-explicit visual representations (shading) is a novel way to test theoretical models of neglect syndrome.

To this end, we used the Polo Mint stimulus in a group of seven patients presenting a left spatial neglect and one patient with a right spatial neglect. If the hypothesis of a cerebral hemispheric difference for the assumption concerning the light source position is correct, then left hemi-neglect patients might posit a default light source position in a location different from the one assumed by normal observers.

2. Methods

2.1. Participants

A total of eight patients participated in the experiment. Four patients had had a first single unilateral stroke (ischemic, $n = 3$; hemorrhagic, $n = 1$) in the right cerebral hemisphere, one in the left cerebral hemisphere (ischemic), and three other patients had a right hematoma (located in the internal capsule, and/or the thalamus, or the basal ganglia, or intra-parenchymal; all patients were right-handed and had no history of psychiatric disorders or dementia. The neuropsychological evaluation of each patient revealed no language disorders and no signs of apraxia or agnosia; none of the patients showed major verbal memory difficulties. All of them had a preserved comprehension of complex sentences. None of them presented hemianopia or any other visual field deficit. We evaluated the severity of the spatial neglect for each patient using a set of clinical tests that is frequently used to assess neglect (Azouvi et al., 2002), including two visuo-motor exploratory tasks (line bisection and letter cancellation), a reading task, and a drawing copy task. In all tasks, the center of the display was located on the mid-sagittal plane of the patients' trunk; they were free to move their head and eyes. The patients' demographic and neurological features are summarized in Table 1.

Fourteen participants (mean age = 57.6 years, SD = 9.9, range = 42–75 years) with no history or evidence of neurological damage served as controls. Twelve of them were right-handed and two were left-handed. We created a program using matlab to test hemianopia in patients. They were asked to detect whether a vertical or a horizontal line was present on a computer screen. Targets were presented in the left, right or both hemi-fields. There was no sign of hemianopia in patients. This was confirmed with the BEN test (Azouvi et al., 2002). All patients had normal or corrected-to-normal visual acuity.

Patient 1 had a right hematoma in the region of the thalamus and near the internal capsule. P1 was a 56-year-old man admitted with left paresis of the upper and lower body; the paresis had resolved at the time of testing. P1 showed little left neglect and had some difficulties maintaining his attention during the neuropsychological evaluation.

Patient 2 had a right ischemic stroke in the region of the temporal and parietal lobes. P2 was a 48-year-old man who presented with mild left hemiparesis and mild left-side extinction; he had a good temporo-spatial orientation with otherwise intact cognitive functions.

Patient 3 had a right hemorrhagic stroke in the region of the frontal and parietal lobes. P3 was a 67-year-old man who initially showed inconsistent signs of visual neglect, weakness in the left upper body and paresis of the left leg.

Patient 4 had a right intra-parenchymal hematoma. P4 was a 68-year-old woman admitted with initial confusion and mild weakness of her left arm. Initial cognitive testing showed severe

Table 1
Demographic and neurological data on the eight patients. For line bisection, positive deviations are rightward, percentages correspond to: ((left distance – half of stimulus line length)/(half of stimulus line length)) × 100.

Patient	Gender/age	Days from lesion onset	Etiology	Locus of lesion (R: Right, L: Left)	Line bisection (% deviation)	Letter cancellation (max 30 Left/30 Right)	Landscape drawing (max 6)	Reading task
1	M/56	90	Hematoma	R. Internal capsule, thalamus	+2.16	24/28	5	+
2	M/48	30	Ischemic	R. Temporal, parietal	+17.39[a]	24/30	4.5	+
3	M/67	45	Hemorrhagic	R. Frontal, parietal	+7.57	24/30	6	+
4	F/68	30	Hematoma	R. Intra parenchimal	+5.22	30/30	4.5	+
5	M/52	30	Ischemic	R. Vertebro basilar, thalamus	+12.98[a]	29/29	6	+
6	M/52	42	Hematoma	R. Basal ganglia, thalamus	+13.2[a]	22/30	4.5	+
7	F/45	60	Ischemic	R. Frontal, parietal	+2.1	27/30	6	+
8	M/62	45	Ischemic	L. Frontal, parietal	−3.2	29/26	4	+

[a] A deviation greater than 11.1% is considered pathological (Bartolomeo and Chokron, 1999). For cancellation tests, left/right correct responses are reported. The landscape drawing, consisting of a central house with two trees on each side, was scored by assigning two points to the house and one point to each tree that was completely copied (Gainotti et al., 1972). For the reading task a "+" means a correct reading of the text (i.e., no dyslexia of neglect).

extinction and mild left neglect. However, at the time of the experiment, the neglect was reduced.

Patient 5 had a right ischemic stroke in the region of the vertebral and basilar artery and the thalamus. P5 was a 52-year-old man who presented initial confusion and impaired memory; he had a left paresis of the upper and lower body.

Patient 6 had a right hematoma in the region of the thalamus and near the basal ganglia. P6 was a 52-year-old man admitted with severe visual extinction and mild neglect. Some personal and extrapersonal neglect that had been largely resolved at the time of testing, although line cancellation showed some remaining omissions on the left side.

Patient 7 had a right ischemic stroke in the region of the frontal and parietal lobes. P7 was a 45-year-old woman who presented with mild left hemiparesis; she was well oriented with otherwise intact cognitive functions.

Patient 8 had a left ischemic stroke in the region of the temporal and parietal lobes. P8 was a 62-year-old man admitted with mild weakness of the right arm. Initial cognitive testing showed right neglect whereas other cognitive functions were apparently normal.

All participants gave informed consent prior to the study, but were naive concerning the specific aims of the experiment.

2.2. General neuropsychological evaluation

The neuropsychological neglect examination found no signs of spontaneous head and gaze deviation toward the right or the left side of the space. All patients presented visuo-spatial and visuo-graphic impairments and their performance on executive function tests was generally mildly impaired (i.e., problems organizing and initiating an action). For the line bisection test positive deviations were rightward for the right-brain-damage patients and leftward for the left-brain-damage patient. The percentage of deviation corresponds to ((left distance − half of stimulus line length)/(half of stimulus line length)) × 100. A deviation greater than 11.1% is considered pathological (Bartolomeo & Chokron, 1999). In our study, bisection deviations ranged from 2.1% to 17.39%. P2, P5 and P6 presented a significant deviation from the mid-point. In the letter cancellation task, all right-brain-damage patients showed a left neglect, characterized by more omissions on the left side of the sheet of paper (and vice versa for the left-brain-damage patient). During the neuropsychological evaluation, patients had to copy a landscape consisting of a central house with two trees on each side; this task was scored by assigning two points to the house and one point to each tree that was completely copied (Gainotti, Messerli, & Tissot, 1972). Three patients (2, 4 and 6) performed poorly on this task (i.e., they omitted important details on the left side of their copy). It is important to note that none of the patients showed any sign of object-based neglect. Patients' performance on this clinical neuropsychological evaluation supported a mild form of neglect in visuo-spatial tasks. Control participants also completed the entire neuropsychological evaluation. In the line bisection test, five of them showed a leftward bias (mean 5.3 mm), which is a well-known phenomenon named "pseudoneglect" (Rueckert, Deravanesian, Baboorian, Lacalamita, & Repplinger, 2002).

2.3. Apparatus

All experiments were conducted on a 13-in. Macbook computer. The monitor was calibrated for luminance (brightness setting at 50% and contrast setting at 100%). It was set at a resolution of 1024 × 768 pixels and ran at a refresh rate of 60 Hz. The experimental stimuli were created with Matlab V.730 (Mathworks, Sherborn, MA, USA) and displayed with the PsychToolbox (V1.05; Brainard, 1997; Pelli, 1997).

2.4. Stimuli

Stimuli were adapted from those used by Gerardin et al. (2007). They were displayed in grayscale. The stimulus consisted of a ring with bright and dark polar contours (luminance of 40 and 1 cd/m^2) displayed on a uniform gray background (20 cd/m^2). The diameter of the outmost circle subtended 7° of visual angle (i.e., 192 pixels). The ring was divided into eight equal sectors (of 45° each). All but one of the sectors was simulated to have the same form, either convex or concave. The light source was simulated in one of four positions, two on the left (–67.5° and –22.5° relative to the vertical) and two on the right (+22.5° and +67.5°). The light sources are therefore 45° apart, but none is located 45° from the vertical because we wanted to avoid the cardinal orientations (horizontal and vertical). The combination of the two shapes (convex and concave) and the four light positions produces a total of eight types of stimuli. The contrast of the contours (bright or dark) was determined according to the desired shape to be displayed and the simulated light source position. Low-pass filter was applied to the stimulus. The filter was Gaussian with a standard deviation of 6 pixels. The combination of the two shapes (convex and concave) and the four light positions produces eight types of stimuli, as illustrated in Fig. 1A. The odd sector could be placed in four different locations on the ring, as illustrated in Fig. 1B.

2.5. Procedure

The experiments took place in the experimenter's office, which was illuminated by dim light coming from a window in front of the participants. They lasted for about 1 h; all patients were able to complete the experimental tasks (i.e., they were able to maintain their attention the whole time). Two experiments were run with the same set of stimuli but with different tasks. In the first experiment, observers had to report the side (left or right) of the odd-shaped sector (left–right experiment, LRE). In the second experiment, observers had to determine whether the odd sector was convex or concave (convex–concave experiment, CCE). In total, a session was composed of 192 stimuli presented in random order. Patients and controls used the space bar on the computer keyboard to respond (go/no-go task). Participants were asked four questions in random order: for the LRE: (1) Is the odd sector on the left? (2) Is the odd sector on the right? And for the CCE: (1) Is the odd sector convex? (2) Is the odd sector concave? In all cases, participants had to press the space bar to answer YES and not press it to answer NO. In short, participants had four little experiments to do, two for the LRE and two for the CCE. Before and after each stimulus, participants had to fixate a central cross, so they maintained their attention in the center of the screen. Throughout the data collection, the experimenter sat on the opposite side of the computer monitor, at a location where she could monitor gaze direction. Before initiating each session, the experimenter ensured that the participant's gaze was directed to the center of the screen. Stimuli were shown for 300 ms (for controls) and for 500 ms (for patients) and then immediately followed by a mask. A training set was presented before each session and no feedback was provided.

Performance in the LRE experiment was measured by the percentage of correct responses, where a correct response occurred when the odd sector was located. In the CCE, there is no objective correct shape decision. Performance was measured by the percentage of correct responses consistent with a light source located above rather than below.

3. Results

In this study, performance was better overall when observers (both patients and controls) had to report which side the odd sector was on (LRE) rather than its shape (CCE). For right-brain-damage patients, the percentage of correct responses was 81.3% (LRE) versus 60.55% (CCE), and for controls this percentage was 80.85% (LRE) versus 61.1% (CCE). This could be related to the advantage in location identification over object recognition (e.g., Kveraga, Ghuman, & Bar, 2007). Moreover, there was no difference between patients' and controls' responses. Before comparing patients' and controls' performance, we did a preliminary analysis of patients' performance when the odd sector was on the left side of the stimulus versus on the right. No difference was found between the two sides of the odd sector ($F(1, 7) < 1$; ns). In other words, patients performed equally well when the odd sector was on the left or on the right. In the remainder of this section, we first analyze the results on the LRE, and then on the CCE.

3.1. Left–right experiment

In the first experiment (LRE), where the two groups (i.e., control participants versus right-brain-damage patients) had to report the position of the differently shaped sector (left or right side of the stimulus), we did not find any interaction between the factors *group* and *position* ($F(1,7) < 1$; ns). This result might be due to a ceiling effect on performance in this first task. However, a further analysis of this result shows that, despite the absence of interaction, the percentage of correct responses for controls when the light source position was left was 83.2% (±14), compared to 79.4% (±16) when it was right; this difference is significant ($F(1, 17) = 11.77$; $p < .003$). In contrast, right-brain-damage patients did not show a significant side bias ($F(1, 17) < 1$; ns).

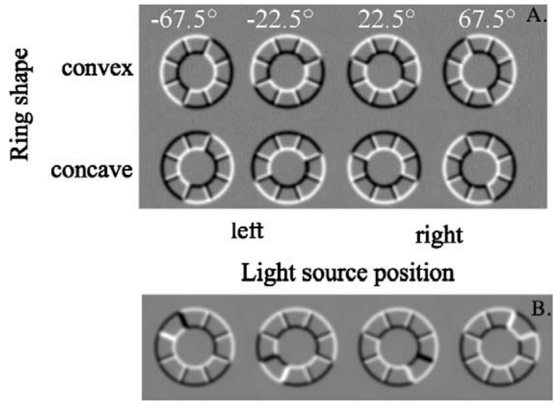

Fig. 1. Stimuli. (A) Variation of the light source for the different stimuli used in the experiment. The images are shown here without the odd sector. For positions −67.5° and −22.5°, the light source position is on the left; for positions 22.5° and 67.5°, the light source position is on the right. (B) The odd sector could be placed at any of four locations on the ring as illustrated in this figure.

3.2. Convex–concave experiment

Fig. 2 represents the light source bias for patients (triangles at the bottom of the figure, $N = 7$ (filled triangles, right-brain-damage patients, $N = 6$; open triangles, left-brain-damage patient, $N = 1$)) and for controls (circles at the top of the figure, $N = 14$). P4 is not represented in this figure; because of the great variability of her results, we believed that she did not understand the task (see below). For each participant (controls and patients), we measured the convexity performance as the percentage of correct responses with a light source positioned above, when the odd sector is concave within a convex ring. In previous work (Mamassian & Goutcher, 2001), we found that there is a one-to-one relationship between the difference in the proportion of convex shapes and the light source bias when the bias is less than 45° in absolute value, assuming that the proportion of convex shapes varies sinusoidally with the light bias.[1] Therefore, differences in the proportion of convex shapes perceived can be translated into the more meaningful light bias variable. A positive angle indicates a right bias and a negative angle indicates a left bias for the light source position. The mean bias for controls is –5.23° ± 4.05SD, which corresponds to the left bias for the light source position observed in other studies with healthy participants. Because of the great variability between and within patients, we will analyze the patients' results one by one.

We used the "Single Bayes" procedure (Crawford & Garthwaite, 2007) to draw inferences concerning the difference between each patient's scores and the control group's. The Single Bayes procedure uses Bayesian Monte Carlo methods to test whether a patient's score is sufficiently below the scores of controls that the null hypothesis that it is an observation from the control population can be rejected. It also provides a point estimate of the percentage of the control population that would obtain a lower score (i.e., a point estimate of the abnormality of the score) and a 95% credible interval for this quantity. The Bayesian method for

[1] In previous work (Mamassian and Goutcher, 2001), we noticed that the proportion of times a convex shape was perceived with different light directions could be well expressed by a raised cosine whose phase parameter is the bias to the left for the assumed light source. We also noticed that this bias was almost never larger than 45° to the left. When the bias is between 0° and 45° to the left, then each of the differences in the proportion of convex shapes for the following pairs of light directions (–22.5; 22.5), (–67.5; 67.5), (–112.5; 112.5) and (–157.5; 157.5) is positive. In fact, there is a quasi-linear relationship between the mean difference in proportion of convex shapes and the magnitude of the bias. Because this relationship is monotonic, we can invert it and infer the light source bias that would be consistent with a particular difference.

standardized differences has the advantages that (1) it can directly evaluate the probability that a control will obtain a more extreme difference score, (2) it appropriately incorporates errors in estimating the standard deviations of the tasks from which the patient's difference score is derived, and (3) it provides a credible interval for the abnormality of the difference between an individual's standardized scores.

3.2.1. Patient 2, patient 3, and patient 7

P2 performed the CCE very slowly and his light source bias was +13.54° ± 2.78SD (i.e., right bias). P3 and P7 performed relatively quickly and their light source biases were, respectively, +4.17° ± 2.80SD (i.e., right bias) and +9.37° ± 4.69 (i.e., right bias). For these three patients, we used the Single Bayes procedure to investigate whether their bias for the light source position was significantly different from the one found for control participants. Patients' scores on the CCE task were compared to the controls' results using the modified *t*-score for single case studies developed by Crawford and Garthwaite (2007). Differences between each patient and the group of control participants were considered significant when the one-tailed probability was equal to or below .05. For P2 (light source bias = +13.54° ± 2.78), the Bayesian *p* value = .0018 < .05. The Bayesian point estimate of the percentage of the control population falling below the patient's score is 0.03%. For P3 (light source bias = +4.17° ± 2.80), the Bayesian *p* value = .02 < .05. Finally, for P7 (light source bias = +9.37° ± 4.69), Bayesian *p* value = .01 < .05. The Bayesian point estimate of the percentage of the control population falling below the patient's score is 2.16%. These three patients present a right bias for the assessment of the light source position, which is significantly different from the bias found in the control group.

3.2.2. Patient 6

P6 performed the experiment relatively slowly. His light source bias was +0.03° ± 2.78°SD (i.e., he presented no bias for the left or for the right). Inferential statistics show that his performance is not significantly different from that of controls (Bayesian *p* value = .1 > .05).

3.2.3. Patient 1 and patient 5

P1's light source bias was −9.92° ± 18.01SD (i.e., left bias) and P5's light source bias was −20.32° ± 25.85SD (i.e., left bias). Their assumed light source position bias is similar to the bias found for control participants but should be interpreted with caution because of the variability of their results. For P1, the Bayesian *p* value = .14 > .05, ns, and for P5, the Bayesian *p* value = .001 < .05. P1's performance is like the one performance of the control group whereas P5 presents an atypical profile.

3.2.4. Patient 8

P8 performed the task very quickly and his light source bias was −23.98° ± 18.3 (i.e., left bias). Although he presented the same profile as the control participants, his performance was significantly different from the one of the control group. His Bayesian *p* value = .001 < .05. Because of the large variability of his results, his profile should be interpreted carefully.

3.2.5. Patient 4

P4's convexity assessment performance varied between 0.44 and 0.54 with considerable variability. She made many errors and when we asked her for her feedback after the experiment she told us that most of her responses were due to chance. Therefore, we calculated the within-subject standard deviation for each position of the light source. As the distribution of her results was greater than 2.5SD around her mean result, her performance was excluded from the analysis and she is not presented in Fig. 2.

4. Discussion

The visual system must quickly and accurately construct a 3D representation of the world. To do so, it relies on prior assumptions or knowledge of statistical regularities in the environment, including homogeneity of texture, surface convexity and so on. Another such prior assumption, the "light from above" assumption, is used to recover shape from otherwise ambiguous shading. Typically, it is assumed that the light source is positioned above and slightly to the left (e.g., Sun & Perona, 1998). The performance of our control group of participants resembled what had been found in previous studies: human observers interpret the shape of shaded objects as if light was coming from above their head, with a bias to the left of the vertical (Gerardin et al., 2007; Mamassian & Goutcher, 2001; Sun & Perona, 1998). Moreover, this left bias for the light source position seems to be independent of the participants' age. Indeed, previous studies were conducted on relatively young populations, whereas the mean age of the control participants in this study was 58 years.

In this study, we evaluated how patients suffering from spatial neglect process the assumed position of a light source in a visual task. The results show a difference in the bias for the assumed light source position for patients with left spatial neglect. Four of the six patients showed a reduction in the normal left bias for the light source position (three of them presented a right bias and one had no bias) and two patients had an "exaggerated" left bias (with very variable performance). Interestingly, the left-brain-damage patient who had a right spatial neglect presented a profile similar to that found for control participants.

A striking finding of our study is that patients with left spatial neglect also had difficulties constructing a visual representation of abstract objects in the scene. Light sources are not physically present in the image, but their position determines the perceived shape of objects. Most of our hemi-neglect patients appeared to struggle to represent the default assumption that a light source is located on the left, thereby generalizing the classical deficit in dealing with objects in the left visual field to abstract objects in the left part of their extra-personal space. Thus, our result suggests that those patients had a representational deficit.

Some studies have demonstrated that spatial neglect can influence imagined space (e.g., Bartolomeo, Thiebaut de Schotten, & Doricchi, 2007; Cristinzio et al., 2009). However, in these studies, patients had to elaborate a mental image from information presented in a familiar visual scene. In our study, the object of interest (the light) was not physically present in the image shown to the participants. It is the interpretation of the image that is biased: light is not seen directly in the image; only the "consequences" of the light source position (i.e., the shading) are visible. Here, we show that neglect patients can also have difficulties using implicit visual objects such as the light source.

The encoding of the light source position, and therefore the origin of the leftward bias, remains unknown. In particular, it is still not clear whether the bias is environmental or biological, although our results with patients presenting an insult to the right hemisphere would favor a biological interpretation.

In future work, it will be interesting to investigate other populations of patients, especially those suffering from a right temporo-parietal lesion but without neglect. We did not include such patients in this study due the rarity of this deficit. Patients with executive problems were excluded from our study because we required our participants to switch between two tasks. A single, simpler task could be envisaged for these patient populations.

Previous studies have shown that neurons in the inferior temporal and intraparietal sulcus of macaques, although they belong to the ventral visual stream, code for depth defined by binocular

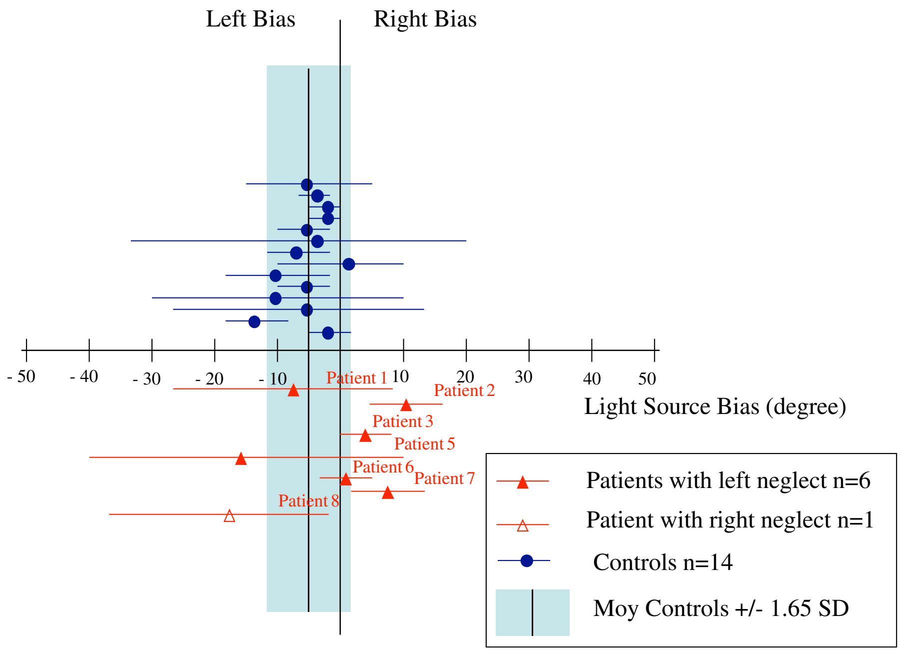

Fig. 2. Magnitude of light source position bias for patients and controls. Triangles represent patients ($N = 7$) and circles represent controls ($N = 14$). Filled triangles represent right-brain-damage patients ($N = 6$) and the open triangle represents the left-brain-damage patient ($N = 1$). Biases are measured in degrees away from the vertical. A negative angle indicates a left bias, and a positive angle indicates a right bias. The dotted bar represents the mean light source bias for controls (±1.65SD as significant threshold).

disparity gradients (Tsutsui, Sakata, Naganuma, & Taira, 2002). These researchers found that neurons sensitive to multiple depth cues were widely distributed in the caudal intraparietal sulcus (CIP), as were those sensitive to a specific depth cue, suggesting that the CIP is involved in the integration of depth information from different sources. In addition, neurophysiological and neuropsychological findings in humans suggest that the CIP plays a critical role in 3D vision by constructing a generalized representation of objects' 3D surface geometry (Sakata, Tsutsui, & Taira, 2005; Tsutsui, Taira, & Sakata, 2005).

Our results support the hypothesis of a hemispheric asymmetry for the representation of illumination. However, some of our patients do not present with a left bias reduction and there is variability in results. It should be noted that reduction in the left bias for the light source position was observed in patients suffering from ischemic as well as from hemorrhagic stroke. Thus, the pathophysiology of the cerebral damage does not play an apparent role in explaining pattern of results. An alternate possibility would be that the magnitude of the left bias for the light source is modulated by the severity of the neglect. However, the patients' performance in the clinical tests does not agree with this view. A more likely explanation is that lesion localization better accounts for the observed performance. Of the six patients with left hemi-neglect three (patients 2, 3, 7) showed significant bias reduction in detecting the light source position. These patients also presented with damage to the fronto-temporo-parietal network. One patient (patient 6) showed no such bias reduction. This patient suffered from a right thalamic hematoma. The remaining two patients showed a bias similar to (patient 1) or greater (patient 5) than controls. These two patients had suffered from a right thalamic stroke. The present results suggest that there is an involvement of a right fronto-temporo-parietal network in the light source bias. They also suggest that areas other than the thalamus or subcortical regions are involved in the representation of light illumination. Our results are consistent with those from previous studies (Hillis et al., 2002; Parton, Malhotra, & Husain, 2005) showing that right subcortical and thalamic ischemic lesions may also produce neglect, associated with diaschisis or hypoperfusion in overlying parietal and frontal areas.

The data obtained from our patients also speak to the question of the anatomical basis of representational neglect. For example, Ortigue et al. (2001) found a pure left representational neglect in the absence of any perceptual neglect in a patient who had suffered a right thalamic stroke. On spatial mental imagery tasks, their patient systematically omitted items located on his left side, but only when a vantage point was given. Their interpretation was that the right thalamus serves as a relay in the processing of spatial visual imagery (i.e., the spatial representation network is not only cortico-cortical but also cortico-subcortical). Our study emphasizes a difference between patients' results depending on their lesion. Patients with a right frontal or parietal lesion seemed to have a right bias while patients with a right thalamic or vertebral lesion seemed to have a normal left bias for the light source position, with very variable results. Our data are not congruent with the Ortigue et al. (2001) data, but this could simply reflect the variability of lesions described under the attentional hypothesis. Moreover, our patients presented large lesions in the right frontal and thalamic lobe, and yet we know that this cortical network sustains attention (Nachev & Husain, 2006). The difference observed between our results and those of Ortigue et al. could also reflect patients' difficulties maintaining their attention throughout the tasks.

In conclusion, the two main contributions of this study are: (1) the support for a hemispheric asymmetry of the representation of illumination, and (2) the proposal that neglect patients may also neglect visual objects that are not physically visible in their visual field. These results demonstrate that spatial neglect should be investigated in a variety of ways, including by testing the representation of world attributes such as light sources that are not present in the visual image. It is important to evaluate this aspect because maybe some of the problems presented by patients with spatial neglect may be due to difficulties processing information that is not present in the visual field or not imagined in the representational scene.

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