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Perception of geometric illusions in hemispatial neglect

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Abstract—A patient with left hemispatial neglect, while completely unaware of features on the left side of figures, nevertheless perceived geometric illusions dependent on these features. Bisection errors were amplified not only by increasing line length, but also by perceived line length induced by these illusions. Bisection of Judd illusion figures was as much influenced by neglected features on the left as by perceived features on the right. These observations demonstrate that geometric illusions are generated through preattentive processes. They also suggest that in visual neglect there may be preattentive processing of location as well as shape information. Copyright © 1996 Elsevier Science Ltd

Key Words: hemispatial neglect; bisection errors; Judd illusion; Müller-Lyer illusion; geometric illusions.

Introduction

Visual illusions, like the Müller-Lyer and Judd illusions, have long been acknowledged to reveal hard wired circuits in the human visual system which mediate early vision. The principles of perceptual organization generating these illusions, however, have been a source of perennial debate within psychology and visual science. We show here that these illusions influenced line bisection performance in a patient with visual neglect. Neglected features contributed as much to her perception of geometric illusions as did attended features, demonstrating that the perception of these illusions proceeds in the absence of attention. Moreover, bisection performance was influenced by perceived line length induced by these illusions. In addition to shedding light on these classical geometric illusions, the current observations provide further evidence that visual perception proceeds to a late level of analysis in the absence of attention or awareness; and they demonstrate, contrary to some accounts of visual neglect, that location information, as well as shape, is represented preattentively.

Method

In order to test the hypothesis that geometric illusions are processed preattentively, a systematic series of observations was made in a single patient with hemispatial neglect who was selected to meet strict criteria which would permit rigorous testing of the hypothesis. Our criteria required that the patient have: (a) dense hemispatial neglect resulting in complete lack of explicit awareness, using a stringent test, of the left side of the illusion figures; (b) no visual field defect; (c) a lesion mainly restricted to posterior association cortex so that line bisection errors resulted only from perceptual neglect without a contribution from directional hypokinesia; and (d) sufficient alertness and motivation, during the period of dense hemispatial neglect, to permit valid testing of bisection performance. In our laboratory, which is actively studying neglect, we identified one patient meeting these criteria during the past 2 years. This patient was studied systematically as follows:

1. Neurological examination and CT scanning established the diagnosis of hemispatial neglect, without visual field defect, due to a large lesion of posterior association cortex largely sparing the dorsolateral prefrontal cortex (Fig. 1).
2. Hemispatial neglect was measured using standard clinical tests including a line bisection task. Line bisection errors were measured for different line lengths.
3. To demonstrate that the patient's bisection errors were due to perceptual neglect, rather than to a motoric bias (directional hypokinesia), she was shown prebisected lines and asked to point to the end of the line closest to the bisection mark [14, 15].

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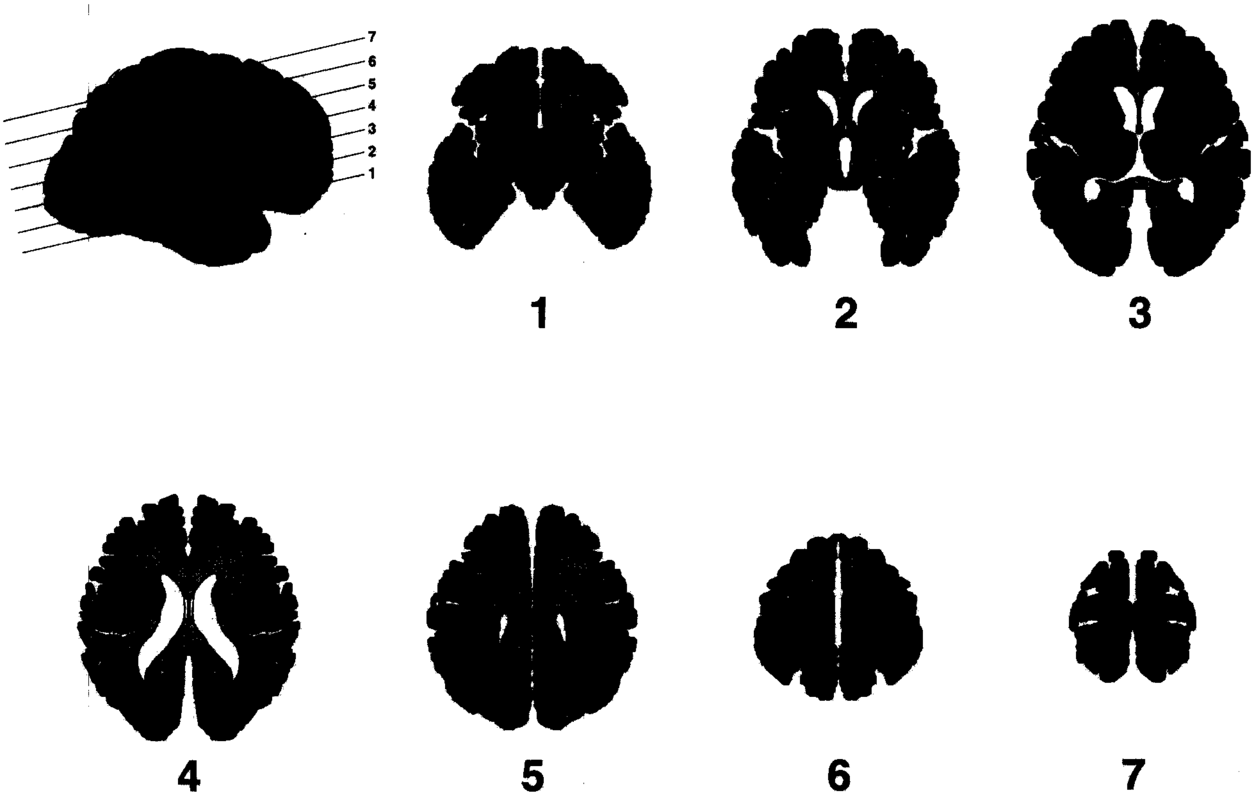


Fig. 1. The extent of the lesion in this patient is shown. The lesion involves the inferior, middle and superior temporal gyri, the inferior and superior parietal lobules as well as the frontal and parietal operculae, but spares the optic radiations, basal ganglia, insula and internal capsule, as well as striate and peri-striate visual cortex.

4. Using the illusion figures to be tested in a bisection task, a same–different two-alternative forced-choice discrimination task was given to assess the patient's explicit awareness of the features on the contralesional (left) side of these figures (Fig. 2).
5. Bisection performance of the Judd and Müller-Lyer illusion figures was measured.
6. A component analysis was performed which calculated the influence of perceived line length in bisection errors of the illusory figures and the relative

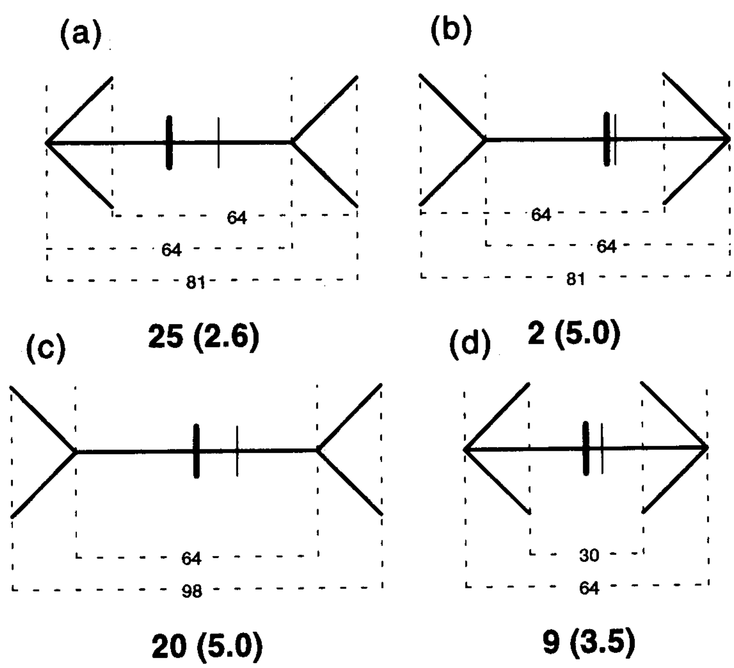


Fig. 2. The four fin configurations producing the Judd illusion (top row) and the Müller-Lyer illusion (bottom row). See text for details.

contributions of left (neglected) and right (perceived) side features in inducing the Judd illusion.

Patient

This 59-year-old woman had suffered a large, recent stroke involving right temporo-parietal cortex (Fig. 1). She was lucid and cooperative and aware that her left arm was paralyzed and that her left leg was starting to get stronger. She reliably detected an object or wiggling finger presented independently in her left visual field, but exhibited consistent unawareness of it (extinction) when another stimulus was simultaneously shown in the right visual field. She had severe neglect in daily activities, and on cancellation tasks, and she bisected lines to the right of midline.

Effect of line length on standard bisection performance

Bisection error was measured for sixteen 4-cm lines and for sixteen 8-cm lines. Bisection error was greater for the longer lines [$t(15)=2.687$, $P<0.02$)].

Test for directional hypokinesia

To determine whether the patient's neglect included a contribution from a motor bias, she was shown lines bisected either in the middle, close to the left or close to the right end of the line and asked to point to (and mark with a pencil) the end of the line closest to the bisection. On trials in which the lines were bisected in the middle, she reliably (15/16) pointed to the left end of the line. Thus, the errors she made when bisecting lines were not due to a motor bias against moving her hand to the left, but rather because she perceived the contralesional side of the line as being shorter [14, 15].

Studies of geometric illusions

Stimuli and procedures

Six weeks after her stroke, we asked her, after obtaining informed consent, to look at four different configurations of line drawings (Fig. 2) and to perform two tasks. In the first she was shown pairs of these figures, some of which differed either on the left or the right, and asked to judge whether they were the same or different. In the second she was asked to bisect them by drawing a line through the center of the shaft of the figures. The first test was used to confirm her lack of explicit awareness of features on the left (contralesional) side of the figures; the second probed whether unattended features on the left side of the figures would influence her experience of the illusions.

Test for explicit awareness

The stimuli in the first task were pairs of the figures shown in Fig. 2 and were sequentially presented, each on 8.5×5.5 in. sheets of paper, with the pair centered slightly below the middle of the page. The patient was asked to report whether the figures in the pair looked the "same" or "different". Half the pairs were same ($n=24$) and half, like those shown in the first two columns of Table 1, were different on either the left ($n=12$) or the right ($n=12$).

Bisection of illusion figures

In the second task, the four stimuli depicted in Fig. 2 were sequentially presented, each again on 8.5×5.5 in. sheets of paper, with the figure centered slightly below the middle of the page. Normal observers are subject to the Judd illusion when the left and right fins on a shaft point in the same direction (Fig. 2a and b). The perceived center of the figure is shifted away from the objective center of the figure either to the right (Fig. 2a) or to the left (Fig. 2b). Note that the objective midline indicated by the bold lines appears off center. When the fins point in different directions, the perceived center is consistent with the objective center of the shaft for normal observers (Fig. 2c and d), but the Müller-Lyer illusion occurs: the shaft in Fig. 2(c) is perceived as being longer than the shaft in Fig. 2(d)[6, 7, 10]. Ten trials for each configuration were presented singly in a randomized order and the patient was asked to bisect the shaft of each figure. The bold line through the shaft is the objective center of the shaft and the numbers within each figure represent the size of the stimuli (in millimeters).

Results

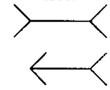
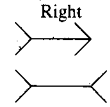
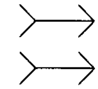
Explicit awareness

When shown figures like those in Table 1, she judged "same" for 23/24 pairs which were the same, and "different" for 11/12 which differed on the right. She failed to notice that the pairs differing on the left were different, and responded "same" for all 12 of these pairs (see Table 1). Thus, this patient evidenced no explicit awareness of the features on the left side of the illusion figures.

Bisection performance

The bold numbers below each of the figures in Fig. 2 represent the bisection errors: mean left minus right score with standard deviations in parentheses. Her bisection errors, which indicates where the patient perceived the center of the shaft to be and depicted by the hairlines through each shaft of Fig. 2, showed that the information from both sides of the figures influenced the perceived

Table 1. S.D.'s performance on the same–different discrimination task

Response	Difference on Left 	Right 	Neither 
Same	12	1	23
Different	0	11	1

center despite the lack of awareness of the features on the left. Had the fin on the left side of the figures not been processed, then bisection performance for Fig. 2(a) and (b) would not have differed from that of the corresponding subjacent figures in the bottom row (since these differed only on their left sides). When the configuration of the fins in the Judd figure favored a perceived center to the right of objective center (Fig. 2a), bisection deviated rightward relative to its control (Fig. 2c). Conversely, when the configuration of the Judd figure favored a perceived center to the left of objective center (Fig. 2b), bisection was further to the left than its control (Fig. 2d). Paired t-tests confirmed these differences showing reliable differences in both pairs in which the visual information differed only on the left of the shape: top left vs bottom left [$t(9)=2.52$, $P<0.05$] and top right vs bottom right [$t(9)=4.30$, $P<0.01$].

The Müller-Lyer figures had an independent effect on the patient's bisection errors. There was a larger bisection error of Fig. 2(c), in which the line shaft is perceived to be longer, than of Fig. 2(d) [$t(9)=5.82$, $P<0.001$]. Bisection error in neglect has been shown to increase with increasing line length [2, 8, 9]. The current observations demonstrate the effect of line length on bisection error in neglect is contingent upon perceived length rather than visual angle, and are consistent with observations that patients make larger bisection errors on more distant lines when angular size is kept constant [3].

Component analyses

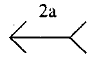
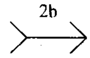
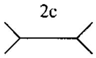
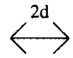
A component analysis, considering both perceived length and the Judd illusion, was done to determine whether the information on the left side of the figures had as much influence on illusion induced bisection errors, as did information on the right side (Table 2). In Fig. 2(d) there are no segments extending beyond the shaft. The bisection error of 9 mm, therefore, serves as a baseline measure of neglect against which the other figures may be compared in order to assess the effect of illusions which might be generated by the features extending beyond the end of the shaft on the neglected (left) side and the non-neglected (right) side. Bisection error is amplified as a function of perceived length due to the Müller-Lyer illusion in Fig. 2(c) which adds an additional bisection error of 11 mm. Figure 2(a) and (b) are intermediate in total length between 2(c) and (d), so an effect on bisection error of 5.5 mm, due to perceived length, is assumed for these two figures. The additional effect of the Judd illusion can then be calculated for Fig. 2(a) and (b). This analysis shows that the Judd effect contributed by the neglected rightward pointing fin on the left side of the shaft of Fig. 2(b) is no less than that produced by the perceived leftward pointing fin on the right side of the shaft in Fig. 2(a). Thus, the Judd illusion induced by the neglected features on the left side of the shaft had as much influence on bisection error as did features on the right, even though the patient had no explicit awareness of these differences in the same–different discrimination task (Table 1).

Discussion

Another investigation on the perception of an illusory figure in neglect has been reported recently by Mattingley *et al.* [12]. A group of neglect patients, with varying degrees of extinction and other symptoms of neglect, was presented with bilaterally-finned figures (i.e. Judd figures), unilaterally-finned figures and regular lines. The results indicated that some patients under some conditions demonstrated preattentive processing of the neglected fins. The authors concluded that there is some processing of the illusion in some patients with hemispatial neglect, but indicated that their study was not suitable for drawing firm conclusions concerning whether geometric illusions can be generated entirely by preattentive processing.

In that study, systematic testing for the lack of explicit awareness of the fins on the left side of the line stem was done in two of the patients, but used a less stringent test than we used here. The patients were asked to describe the figures after they did the bisection on each trial. Thus, the patients' attention was focused on the middle of the line before they were required to report what the figures looked like. Our same–different two alternative forced-choice discrimination task permitted more potential for processing of the left side of the figures (since there was no demand to focus attention on the middle of the figures before making the judgment), and used a same–different judgment which is known to reveal more processing of neglected information than does verbal report [16]. In our study, therefore, we could be more confident that

Table 2. Component analyses of bisection errors computing the effect on bisection of perceived length, and comparing the effects induced by neglected features on the left with those induced by perceived features on the right

Figure	Total Bisection Error	Rightward Bias	Amplification by Perceived Length	Judd Illusion
2a 	25	9	+5.5	+10.5
2b 	2	9	+5.5	-12.5
2c 	20	9	+11	0
2d 	9	9	0	0

the influence of the left sided features in generating the illusions occurred in the absence of any explicit awareness of these features. Moreover, while the study by Mattingley *et al.* [12] did reveal some influence of the left side of the figures, it did not permit a quantitative comparison of the influence of neglected and attended features on line bisection performance. The component analysis applied in the current study demonstrated that neglected features on the contralesional side of the figures were as effective in supporting the illusions as were perceived features on the ipsilesional side of the figures.

While the study of Mattingley *et al.* [12] was intended to examine the processing of illusory figures across the spectrum of the neglect syndrome, our study used a single case design in a patient with hemispatial neglect selected to test, specifically, the hypothesis that geometric illusions are processed preattentively. Our patient's performance revealed that neglected features, entirely excluded from awareness, not only influenced the perception of geometric illusions, but were as effective in generating these illusions as attended features that were perceived. A new observation in the current study is that the effect of line length on bisection error in hemispatial neglect can be based upon perceived length, not simply on visual angle, and is entirely consistent with a recent observation demonstrating that with more distant lines, neglect patients make larger bisection errors when the angular size is kept constant [3].

In summary these observations indicate that geometric illusions are generated in response to information processed preattentively. In addition to being informative concerning the origin of these geometric illusions, the current findings compliment a growing literature from the study of visual neglect indicating extensive preattentive processing of visual and semantic information [1, 4, 5, 11, 12, 13]. They extend earlier reports by showing, within a single object, implicit processing of shape information that influences the perception of other parts of the same object. Another important new finding is that location information, as well as shape information, is processed preattentively. It has been suggested that, while there is preattentive processing of shape information in neglect, awareness of that shape as a distinct object fails because contralesional location information, necessary to distinguish the object as a distinct token, is degraded [1]. In Fig. 2(a) and (b), however, the two fins on each side of the stem have identical shapes. The only difference which distinguishes them, and upon which the Judd illusion depends, is that they are in different locations. The influence of the Judd illusion on bisection, in this case, implies that not only is the shape of the left side of the figure implicitly processed, but that its location is represented as well.

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