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Size perception in hemianopia and neglect

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Summary

Some debate remains as to whether underestimation of the horizontal size of objects in the left part of visual space is a general disturbance in spatial neglect. The issue is unclear because size perception may be influenced by factors other than neglect, e.g. visual field defects such as hemianopia. To disentangle these effects, we compared the performance of patients with pure neglect, pure hemianopia or both on the same size-comparison test. Whereas pure neglect was accompanied by misperception of horizontal object size, patients with pure hemianopia showed an even greater impairment of size perception. Accordingly, the area of maximum lesion overlap of these patients with impaired size perception was not centred around the parietotemporal cortex, which is typically associated with spatial neglect, but rather was found in the occipital lobe (Brodmann areas 17 and 18). The results suggest that spatial neglect is not an inevitable consequence of distorted size perception. The perceptual distortion of objects in the leftward parts of visual space is not sufficient to account for the occurrence of visuospatial neglect.

Keywords: spatial neglect; hemianopia; size perception; brain damage; human

Abbreviations: hor–hor = horizontal rectangles horizontally arranged; hor–ver = horizontal rectangles vertically arranged; PSE = point of subjective equality; ver–hor = vertical rectangles horizontally arranged; ver–ver = vertical rectangles vertically arranged

Introduction

Several authors have proposed a distortion of visual space in either the representational (Bisiach *et al.*, 1994, 1996) or the perceptual domain (Gainotti and Tiacci, 1971; Milner, 1987; Halligan and Marshall, 1991; Milner and Harvey, 1995) in patients with unilateral left neglect after brain damage. Most of these studies were based on the classical shift in line bisection tasks observed by Heilman and Valenstein (Heilman and Valenstein, 1979). They found that neglect patients deviated towards the right when setting the midpoint of a horizontal line and that their errors increased in more leftward parts of visual space. Milner concluded that neglect patients perceive space as compressed, increasingly so in more leftward parts (Milner, 1987). One implication is that neglect patients should perceive two identical objects that are horizontally arranged as different in size: the left object should appear shorter than the object on the right. Indeed, Milner and Harvey found that three patients with neglect estimated two rectangles as equal in size only when the left rectangle was up to 25% larger than the right rectangle (Milner and Harvey, 1995). Kerkhoff replicated this finding with other neglect patients (Kerkhoff, 2000).

Bisiach and colleagues asked patients with neglect to set the end-points of an imagined line on the basis of the given midpoint. The patients misplaced the end-points such that the longer segment lay on the contralesional side of the midpoint and the shorter on the ipsilesional side. The authors attributed this finding to a logarithmic scaling of space representation, with compression on the ipsilesional side and extension on the contralesional side (Bisiach *et al.*, 1994, 1996). Halligan and Marshall proposed a different model of space perception in patients with neglect (Halligan and Marshall, 1991). On the basis of a rightward visuospatial localization error in one patient with neglect, they suggested a uniform compression of space.

In contrast to the above studies, others found no distortion of space perception in neglect (Bisiach *et al.*, 1998; Doricchi and Angelelli, 1999; Karnath and Ferber, 1999). Two possible reasons for the discrepant findings have been suggested. Karnath and Ferber speculated that the reported misperception of object size does not result from neglect but rather from (i) disturbed processes in object perception occurring independently of neglect patients' impaired space perception, or (ii) hemimicropsia, which denotes the underestimation of the size of objects located in one hemifield (Karnath and

Ferber, 1999). Two recent reports of brain-damaged patients with hemimicropsia supported the view that neglect *and* distortion of size perception are not necessarily related (Cohen *et al.*, 1994; Frassinetti *et al.*, 1999). The patients underestimated the horizontal size of objects in their contralesional space without any concomitant signs of spatial neglect. Doricchi and Angelelli attributed the misperception of horizontal space in patients with neglect to the confounding effect of a primary visual field defect (Doricchi and Angelelli, 1999). They pointed out that, in most of the studies reporting distortion of size perception (Halligan and Marshall, 1991; Bisiach *et al.*, 1994; Milner and Harvey, 1995), the participating patients suffered not only from neglect but also from hemianopia. In their study, Doricchi and Angelelli asked patients with pure neglect, pure hemianopia or both to reproduce a given horizontal distance (Doricchi and Angelelli, 1999). Only patients with both neglect and hemianopia showed significant contralesional overextension and ipsilesional underextension. The authors concluded that only the combination of posterior brain lesions causing neglect *and* hemianopia distorts the representation of horizontal space. Though the authors' finding is convincing, there are still some questions that are not answered by their study.

In order to substantiate the conclusion that only the combination of neglect and hemianopia leads to distorted size perception, it is necessary to know the individual effects of left-sided neglect and left-sided hemianopia. Doricchi and Angelelli included only one patient with right occipital damage and consequent leftward hemianopia; the four other patients with visual field defects suffered from rightward hemianopia following left-sided brain damage. Therefore, it appears possible that the group analysis did not reveal any effect of right-sided brain damage and left-sided hemianopia because the majority of patients suffered from left-sided brain damage.

Secondly, the patients in Doricchi and Angelelli's study were asked to make their distance judgements manually. Consequently, motor impairments (optic ataxia, directional hypokinesia) could have influenced the patients' responses in the size-comparison task. We wanted to avoid this problem by employing a perceptual task like that used by Milner and Harvey (Milner and Harvey, 1995). In this task, the patients see two rectangles on a screen and indicate verbally which one is shorter or longer. Thirdly, Doricchi and Angelelli tested size estimation only along the horizontal axis. Thus, a general disorder in size perception (such as dysmetropsia) rather than neglect or hemianopia might have contributed to their results. It is not possible to tell whether their subjects' deficits lay in judging the size (dysmetropsia) or the distance of objects: objects may appear smaller because they are perceived as closer than they really are (assuming that the size of the retinal image remains the same).

In the present study, we tried to circumvent these constraints by using a purely perceptual task, as employed by Milner and Harvey (Milner and Harvey, 1995), and by including patients with leftward hemianopia following infarction in the territory of the right posterior cerebral artery. Moreover, our study attempted to identify the brain area(s) subserving size perception by examining the superposed images of brain lesions of those subjects suffering from impaired horizontal size perception.

Methods

Subjects

We examined six healthy control subjects and 20 patients with right-brain damage. The 20 patients with brain damage comprised seven with neglect but without hemianopia, five patients with neglect and hemianopia, five with hemianopia but without neglect following infarctions in the territory of the posterior cerebral artery, and three without neglect or hemianopia. Demographic and clinical data of all patients are reported in Table 1. Superimposed brain lesions of patients with neglect, patients with pure hemianopia and patients with both neglect and hemianopia are shown for each group separately in Fig. 1. Visual field defects were measured by Tübingen perimetry. Patients were classified as having neglect when they showed clinical behaviour typical of neglect, such as (i) spontaneous deviation of the head and eyes towards the ipsilesional side; (ii) orienting towards the ipsilesional right side when addressed from the front or the left; and (iii) ignoring contralesionally located people or objects; and when they fulfilled the criterion in at least three of the following tests.

Letter cancellation test (Weintraub and Mesulam, 1985)

Sixty target letters 'A' were distributed amid distractors on a horizontally oriented DIN A4 page, 30 on the right half of the page and 30 on the left half of the page. The subjects were asked to mark all of the letters 'A' on the whole page. The maximum score within each half-field was 30. Patients were classified as suffering from spatial neglect when they omitted at least five left-sided targets.

Bells test (Gauthier et al.*, 1989)*

This test consists of seven columns each containing five targets (pictures of bells) and 40 distractors. Three of the seven columns were on the left side of the DIN A4 sheet (making 15 targets); one was in the middle and three were on the right (15 targets). The patients were asked to cross out all the bells; the maximum score for each half-field was 15. More than five left-sided omissions indicated neglect.

Baking Tray Task (Tham and Tegnér, 1996)

Patients had to place 16 identical items as evenly as possible on a blank test sheet (DIN A4). The number of items distributed within each half sheet was reported and the ideal score was 8. Tham and Tegnér considered any distribution

Table 1 *Demographic and clinical data of patients with pure neglect (Patients NEG1–7), neglect and hemianopia (Patients NEG+HA1–5) and patients with pure hemianopia (Patients HA1–5)*

Patient	Age (years)	Sex	Days after stroke	Letter cancellation		Bells test		Baking tray task		Copying
				Left	Right	Left	Right	Left	Right	
NEG1	75	M	40	4	23	0	11	5	11	6
NEG2	79	F	24	3	28	15	14	1	15	2
NEG3	59	M	21	0	15	0	10	7	9	4
NEG4	63	M	75	4	30	0	11	1	15	3
NEG5	65	M	510	21	29	11	12	2	14	2
NEG6	63	F	10	0	11	0	2	9	7	5
NEG7	77	F	77	0	21	0	5	0	16	3
NEG+HA1	69	M	14	0	16	0	8	6	10	6
NEG+HA2	63	M	39	0	18	0	11	1	15	7
NEG+HA3	79	F	4	0	10	0	8	0	16	7
NEG+HA4	69	F	41	8	28	0	13	1	15	5
NEG+HA5	64	F	28	0	15	3	9	2	14	4
HA1	82	F	17	28	30	n.a.	n.a.	7	9	1
HA2	80	M	27	25	24	n.a.	n.a.	8	8	0
HA3	65	F	22	29	29	14	14	7	9	1
HA4	80	M	34	30	28	15	15	7	9	0
HA5	48	F	3	30	29	14	15	8	8	0

Letter cancellation (Weintraub and Mesulam, 1985): number of detected target letters on each half of the test sheet (n_{max} = 30 on either side). Bells test (Gauthier *et al.*, 1989): number of target letters detected on each half of the test sheet (n_{max} = 15 on either side). Baking Tray Task (Tham and Tegnér, 1996): patients had to place 16 identical items as evenly as possible on a test sheet (DIN A4). The number of items distributed within each half of the sheet is reported. Copying task: the patients were asked to copy a complex multi-object scene consisting of four elements; for scoring details see Methods. F = female; M = male; n.a. = task not administered.

that was more skewed than seven items in the left half and nine on the right to be a sign of neglect (Tham and Tegnér, 1996).

Copying task

Patients were asked to copy a drawing of a complex multi-object scene consisting of four figures (a fence, a car, a house and a tree), two in each half of a horizontally oriented DIN A4 paper. Omission of at least one of the left-sided features of each figure was given a score of 1 and the omission of one whole figure was scored 2 for each omitted figure. One additional point was given when left-sided figures were drawn on the right side. The maximum score was 8. Patients were diagnosed as suffering from spatial neglect when they achieved a score higher than 1.

Materials

Patients viewed a computer screen from a distance of 57 cm. At this distance 1 cm corresponds to 1° of visual angle. As in Milner and Harvey's paradigm (Milner and Harvey, 1995), two different sets of patterns were generated: horizontal rectangles and vertical rectangles. A pair of horizontal or vertical rectangles was presented in each trial. Four conditions were run: (i) horizontal rectangles arranged horizontally, i.e. one rectangle on the left half of the screen and the other one on the right (the 'hor–hor' condition; Fig. 2A); (ii) horizontal rectangles arranged vertically, i.e. one rectangle in the upper half of the screen and the other in the lower half ('hor–ver'; Fig. 2B); (iii) vertical rectangles arranged horizontally ('ver–hor'; Fig. 2C); and (iv) vertical rectangles arranged vertically ('ver–ver'; Fig. 2D). The centres of the rectangles were 9 cm apart, i.e. 4.5 cm left/right or up/down from the centre of the screen.

All rectangles were shown in outline form. Following Milner and Harvey (Milner and Harvey, 1995), we used a standard rectangle 4 cm wide and 0.5 cm high. Ten shorter rectangles were produced by compressing the standard one by steps of 5% (2 mm) to 50% of the width of the standard rectangle (2 cm). For each trial, the standard rectangle was shown in one half of the screen and an identical or shortened one in the other half of the screen. All possible combinations of the standard rectangle with the 10 shorter rectangles plus one identical pairing yielded 21 pairings. All pairs were shown for an unlimited time. Within each condition, trials were arranged in five blocks. Each block consisted of all 21 pairings in a randomized order. All subjects completed the full five blocks for each condition.

Subjects were falsely informed that none of the pairings consisted of two rectangles of the same size. A verbal two-alternative, forced-choice comparison (left/right or up/down) about the size was requested for each trial; no other response was permitted. All subjects were tested twice with a minimum

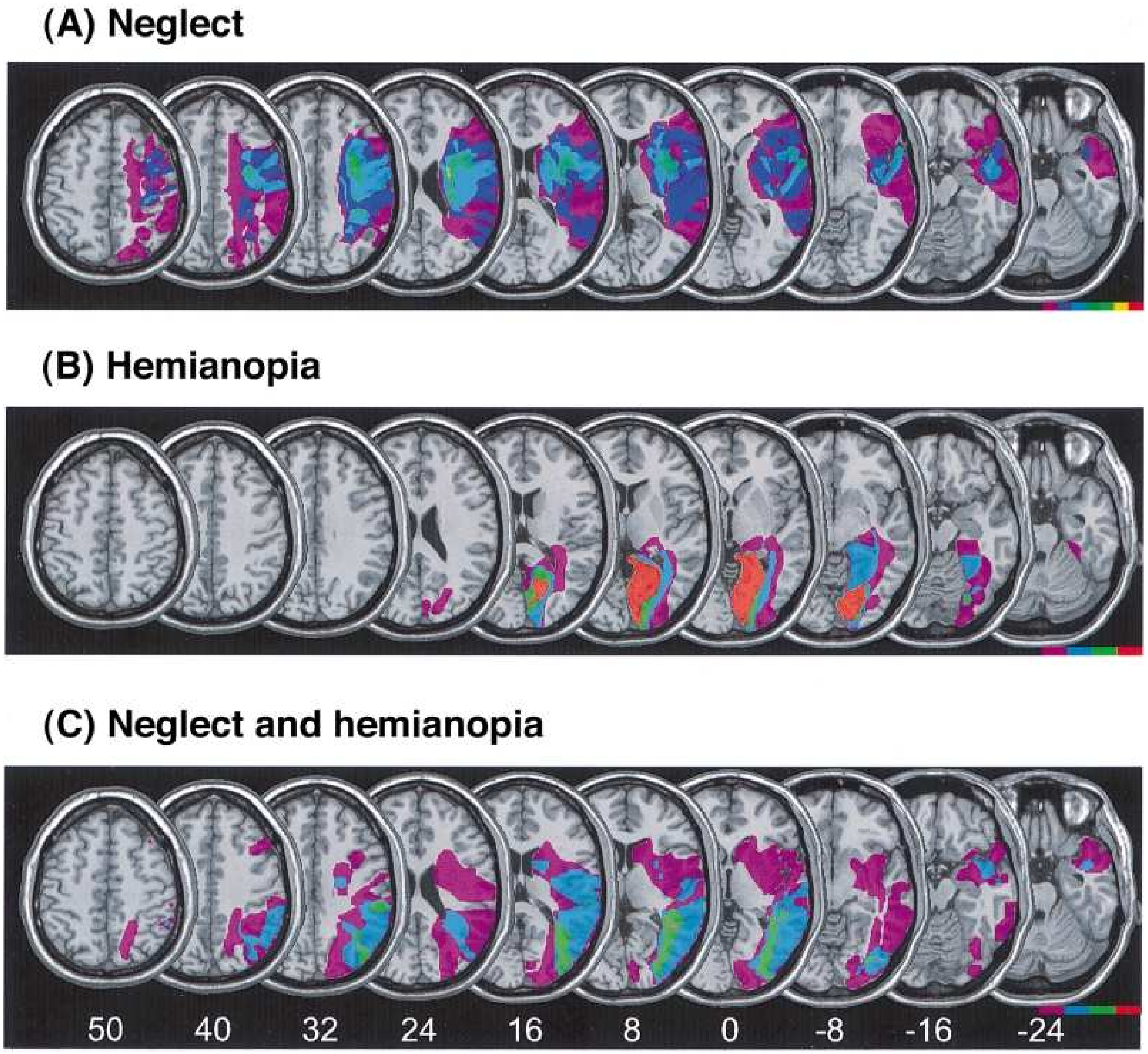

Fig. 1 Superimposed overlapping brain lesions of patients with (**A**) pure neglect, (**B**) pure hemianopia and (**C**) neglect and hemianopia. Using MRIcro software (www.psychology.nottingham.ac.uk/staff/cr1/mricro.html), the lesions were mapped on slices of a template MRI scan from the Montreal Neurological Institute (Rorden and Brett, 2001), which was normalized to Talairach space (Talairach and Tournoux, 1988). The *z* coordinates of each transverse section are given. The number of overlapping lesions is indicated by colour-coding increasing frequencies from violet to red. (Patients HA1 and NEG+HA2 both had CT-documented unilateral right hemisphere lesions. Unfortunately, their scans were lost before detailed lesion location analysis. According to the written neuroradiological reports, Patient H1 had an infarct in the territory of the right posterior cerebral artery, and Patient NEG+HA2 had an infarct in the territory of the right middle cerebral artery.)

interval of 1 day between the two sessions. In one session, subjects were asked to indicate verbally the smaller rectangle; in the other session they were asked to indicate verbally the larger member of each pair. Consequently, each pair of rectangles was presented 10 times; subjects were asked for the larger rectangle five times and for the smaller one five times.

Results were analysed according to Milner and Harvey's scoring procedure (Milner and Harvey, 1995). First, we calculated a point of subjective equality (PSE) by least-squares fitting to a sigmoid curve. We computed the following function for each session (smaller or larger) separately:

$$P(ch) = \frac{1}{1 + e^{-\mathrm{k}\cdot(x - equal)}}$$

where *P(ch)* denotes the probability of the choice 'left' or 'down' when the subject was asked which rectangle was smaller, or the probability of the choice 'right' or 'up' when the subject was asked which rectangle was the

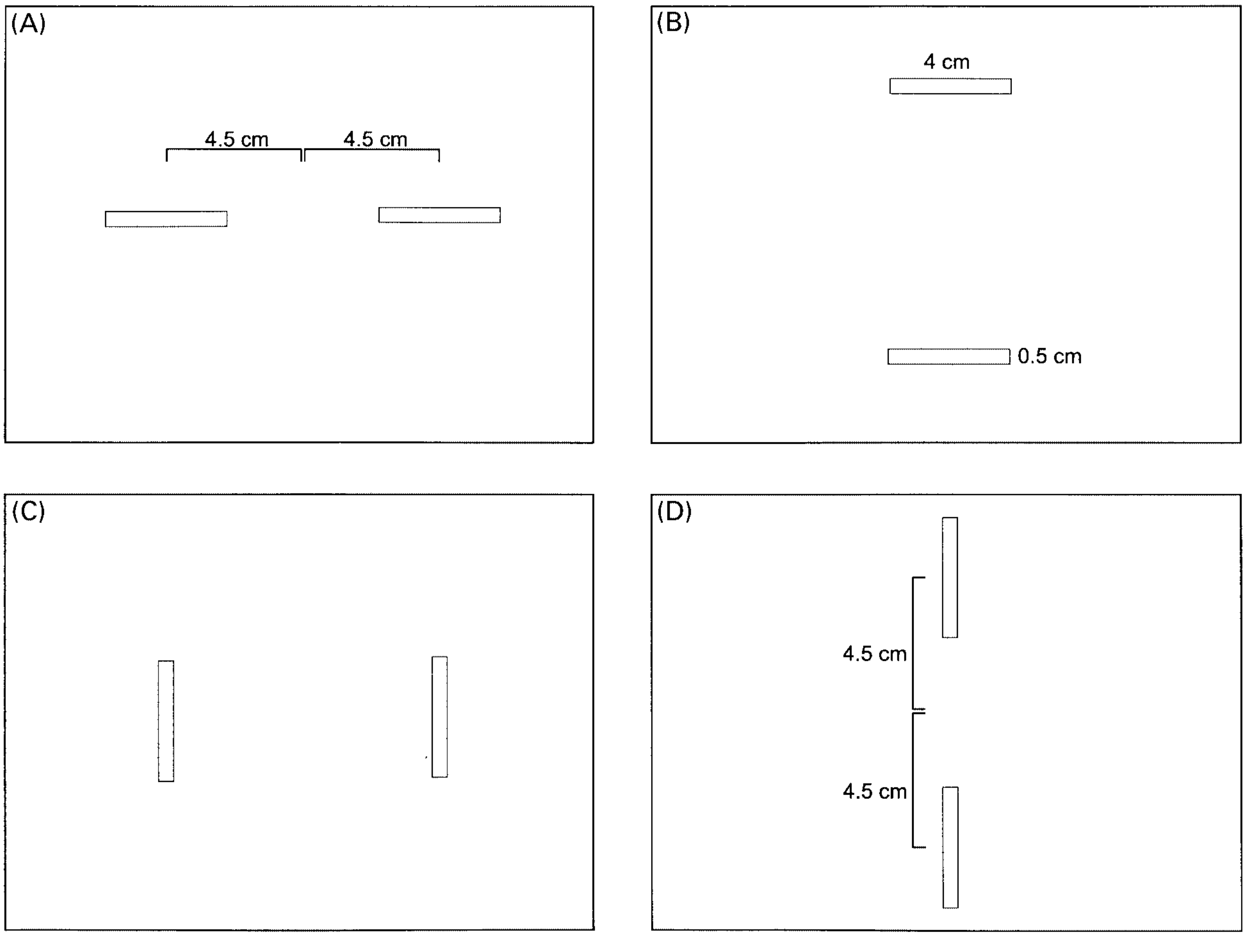

Fig. 2 Schematic drawing of the four stimulus conditions. (**A**) Condition hor–hor: two horizontal rectangles arranged horizontally, with centres 4.5 cm (4.5°) left and right from the centre of the screen, respectively. (**B**) Condition hor–ver: horizontal rectangles arranged vertically, to control for a general problem in estimating horizontal object size. (**C**) Condition ver–hor: vertical rectangles arranged horizontally. (**D**) Condition ver–ver: vertical rectangles arranged vertically.

larger; x is the size difference between the two rectangles; *equal* denotes the size difference between the rectangles for which $P(ch) = 50\%$; and k is the slope of the function at $P(ch) = 50\%$.

Secondly, we calculated an error score in the same way as did Milner and Harvey (Milner and Harvey, 1995). A score of $S + 1$ was given when the subject made an error, where S is the number of steps by which the rectangles differed on that trial. Overestimation of the right (or upper) rectangle was assigned a positive value; overestimation of the left rectangle (or lower) was assigned a negative value (for details, see Milner and Harvey, 1995). We calculated an average error score for each pairing within each condition and each session. We then computed a cumulative error score over all trials for each condition and each session separately. Finally, for each condition the cumulative error scores of the two sessions were averaged. The three neglect patients in Milner and Harvey's study (Milner and Harvey, 1995) achieved error scores between 9 and 24 when comparing horizontal rectangles.

Results

Point of subjective equality

Horizontal rectangles

Performances of all subject groups in matching horizontal rectangles (condition hor–hor) are shown in Fig. 3A, upper panel. We plotted the probability that subjects would judge the left rectangle to be smaller as a function of the size difference between the two rectangles. The control subjects, i.e. healthy subjects and patients with right-brain damage without neglect or hemianopia, showed no apparent difficulty in judging the horizontal size of two rectangles. The PSE averaged over both sessions was –0.09.

For patients with pure neglect, the PSE averaged over both sessions was 0.22. This means that the left rectangle had to be on average 0.22 cm or 5.5% longer than the rectangle on the right in order to appear equal in size. For patients with neglect and hemianopia, the PSE averaged over both sessions was 0.39, indicating that they perceived the two rectangles as equal when the left one was 0.39 cm or 9.8% longer.

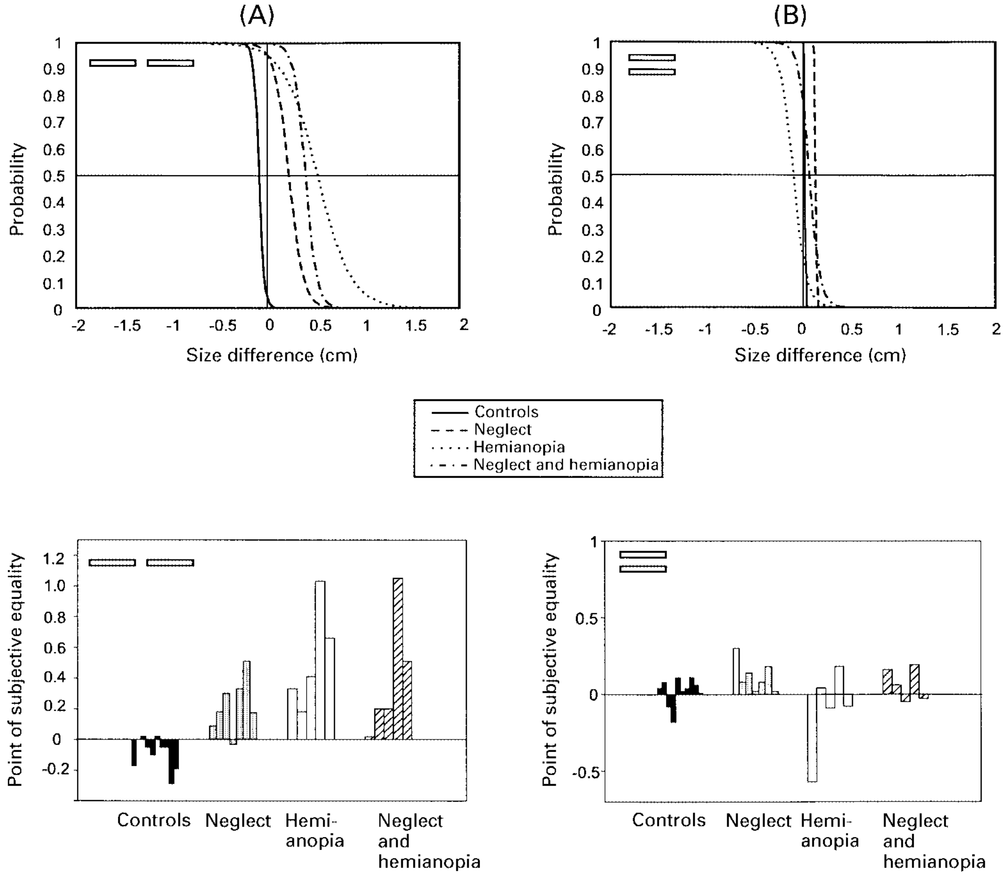

Fig. 3 Mean performance of all subject groups (top) and individual results (bottom) when matching horizontal rectangles that were arranged horizontally (**A**) or vertically (**B**). (**A**) *Upper panel*: probability that the left rectangle will be judged smaller as a function of the size difference between the two rectangles (negative values denote a stimulus smaller on the left; positive values indicate a stimulus larger on the right); *lower panel*: individual points of subjective equality. (**B**) *Upper panel*: probability that the lower rectangle will be judged smaller as a function of the size difference between the two rectangles (negative values denote a smaller stimulus below the centre of the screen); *lower panel*: individual points of subjective equality.

Patients with pure hemianopia displayed the most difficulty with this task. The PSE was 0.52, which means that the left rectangle needed to be greater than 0.5 cm or 13% longer. Individual results of all subjects are shown in Fig. 3A, lower panel.

Because of heterogeneous variance in our data (Levene test for condition hor–hor, $P = 0.023$), we employed non-parametric tests for further analysis. A Kruskal–Wallis *H* test revealed significant differences between subject groups in this condition ($\chi^2 = 17.26$; $P = 0.001$). The six *post hoc U* tests disclosed significant differences between controls on the one hand and patients with neglect, patients with hemianopia and patients with both neglect and hemianopia on the other hand ($P = 0.003$ for each). All other comparisons failed to reach significance.

In contrast to these findings, the analysis of horizontal rectangles that were arranged vertically (hor–ver; Fig. 3B, upper panel) showed no significant differences between subject groups ($\chi^2 = 4.86$; $P = 0.183$). This indicates that subjects were generally able to estimate the horizontal size of objects correctly.

Vertical rectangles

Similar tests with vertical rectangles revealed whether the observed deficit of size perception was constrained to the horizontal axis and whether subjects consistently underestimated the distance to objects located in the left half of visual space. Figure 4 presents the results. Subject groups differed significantly only in their judgements of horizontally arranged rectangles ($\chi^2 = 14.61$; $P = 0.002$; Fig. 4A, upper panel). *Post hoc U* tests revealed significant differences between controls and patients with both neglect and hemianopia ($P = 0.003$) and between the latter group and patients with pure neglect ($P = 0.004$). This means that, compared with controls (PSE = 0.05) and patients with pure neglect (PSE = 0.07), patients with neglect and hemianopia (PSE = –0.2) perceived vertical rectangles on

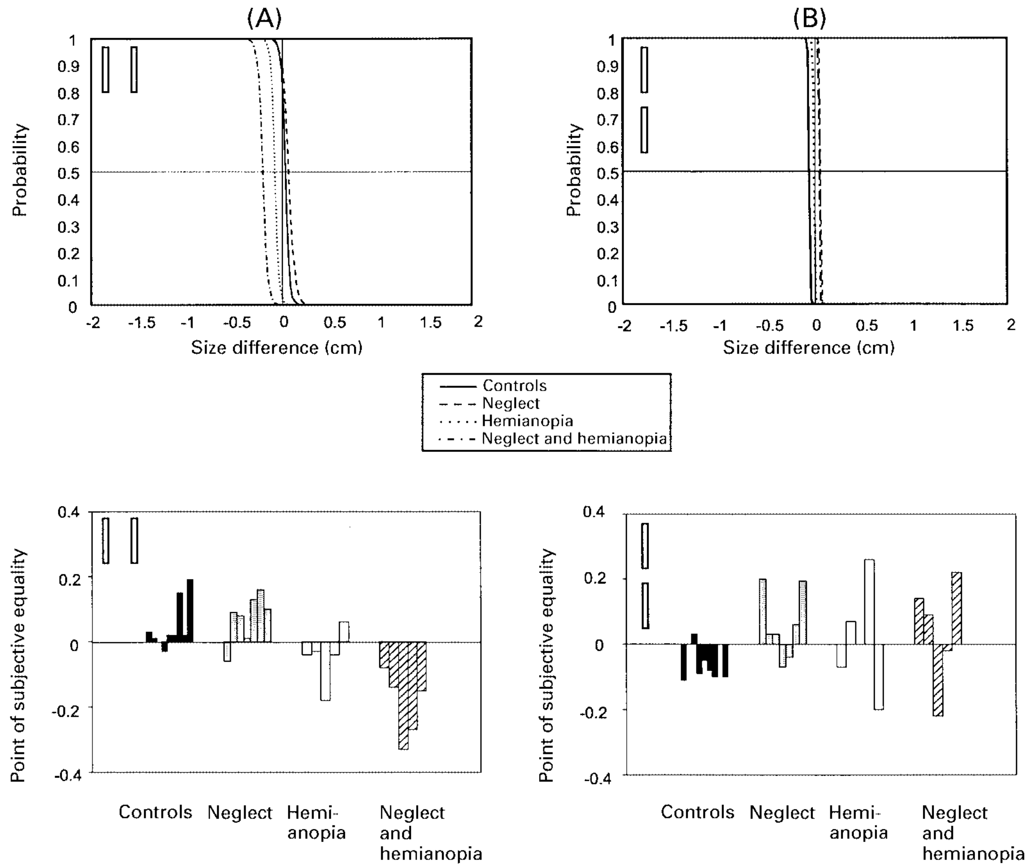

Fig. 4 Mean performance of all subject groups (top) and individual results (bottom) when comparing vertical rectangles that were arranged horizontally (**A**) or vertically (**B**). (**A**) *Upper panel*: probability that the left rectangle will be judged smaller as a function of the size difference between the two rectangles; *lower panel*: individual points of subjective equality. (**B**) *Lower panel*: probability that the lower rectangle will be judged smaller as a function of the size difference between the two rectangles; *lower panel*: individual points of subjective equality.

the left half of the screen as taller. It follows that patients with neglect and hemianopia do *not* suffer from general underestimation of the distance of left-sided objects. If this were so, the vertical size of left-sided objects would appear *smaller.*

Error score

A very similar pattern of results was found for the error score introduced by Milner and Harvey (Milner and Harvey, 1995). When comparing horizontally arranged horizontal rectangles (condition hor–hor), patients with neglect had an average error score of 2.8 (SD = 2.44), patients with both syndromes (neglect and hemianopia) had an error score of 6.9 (SD = 8.46), and patients with hemianopia alone had an error score of 9.5 (SD = 7.27). In contrast, the error score for controls was –0.8 (SD = 0.79).

Four Kruskal–Wallis H tests were performed to compare the groups for each condition separately. Again, we found significant differences between subject groups when subjects compared the size of horizontal rectangles that were arranged horizontally ($\chi^2 = 17.6$; $P = 0.001$) and when subjects compared vertical rectangles that were arranged horizontally ($\chi^2 = 18.92$; $P < 0.001$). In the remaining two conditions (hor–ver, ver–ver) the groups did not differ significantly. In the condition hor–hor the only significant differences after Bonferroni correction were found between controls on the one hand and patients with pure neglect ($P = 0.002$), patients with neglect and hemianopia ($P = 0.004$) and patients with pure hemianopia ($P = 0.003$) on the other hand. This means that all three patient groups underestimated the horizontal size of objects in the left half of the screen.

When subjects matched the size of horizontally arranged vertical rectangles, three significant group differences were found: control subjects differed significantly from patients with both neglect and hemianopia ($P = 0.003$), and patients with pure neglect differed from patients with hemianopia ($P = 0.004$) and from patients with both neglect and hemianopia ($P = 0.003$). Thus, again, patients with both neglect and hemianopia overestimated vertical rectangles on the left half of the screen compared with controls and patients with pure neglect.

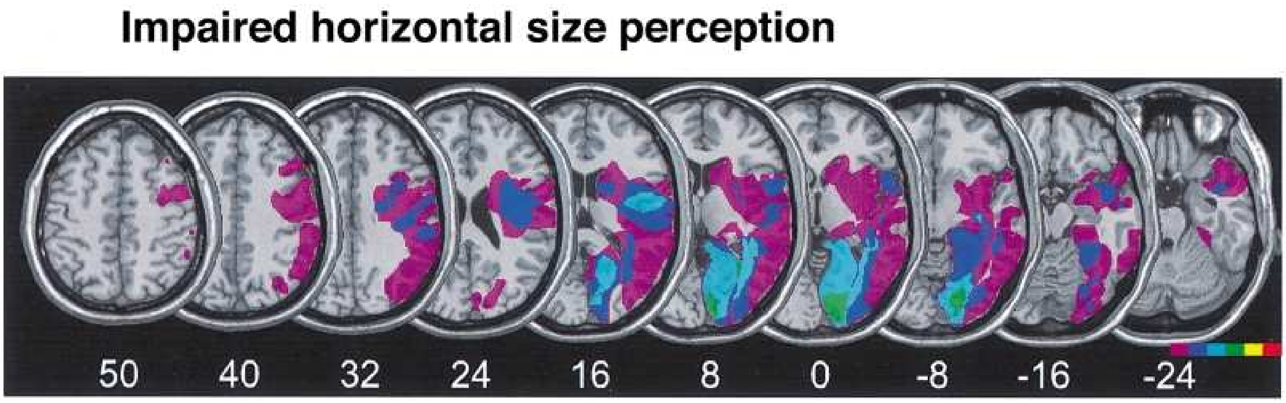

Fig. 5 Superimposed overlapping brain lesions of all six patients with impaired horizontal size perception. Abnormal performance was defined as any PSE greater than 0.4. The same MRIcro software and the same normalized template MRI was used as in Fig. 1. The number of overlapping lesions is illustrated by colour-coding increasing frequencies from violet ($n = 1$) to red ($n = 6$).

Lesion site

What lesion site is associated with misperception of horizontal object size? To answer this question, a criterion for normal perception of object size is needed. Because studies with large populations of unselected brain-damaged patients are still lacking, we defined abnormal size perception according to the results of a recent study in which the performance of neglect patients in a purely perceptual size matching task was related to the brain lesions of these patients. Irving-Bell and colleagues (Irving-Bell *et al.*, 1999) employed a task in which patients had to choose which of three horizontal lines on one lateral half of a page matched a separate, single horizontal line on the other half of the page. They found that, when the set of comparison lines was on the left, patients mostly selected a line that was 11.1% longer than the sample on the right. The authors related this perceptual distortion to the brain lesions of their patients, which were in the white matter in the vicinity of Brodmann areas 18 and 19. Accordingly, we defined abnormal size perception as an underestimation of the left-sided stimulus of at least 10% (PSE = 0.4)

Figure 5 shows the superimposed lesions of the six patients whose PSE was beyond this cut-off criterion (Patients NEG6, NEG+HA4/5 and HA3–5). The most frequent overlap was found in Brodmann areas 17 and 18.

Discussion

The present results demonstrate that patients with pure neglect and patients with neglect and hemianopia differed significantly from controls when matching horizontal rectangles. Thus, we replicated the observation of Milner and Harvey, who found this deficit in one patient with pure neglect and two patients with neglect and hemianopia (Milner and Harvey, 1995). However, we also found that patients with *pure* hemianopia after right-sided lesions showed impaired size perception. Moreover, these distortions appeared to be even more severe than those shown by the neglect patients with and without hemianopia (although there was no statistically significant difference between patient groups). This underestimation of the left-sided stimulus in patients with pure hemianopia is consistent with the findings of Zihl and von Cramon, who asked patients with unilateral brain damage and homonymous hemianopia to judge the horizontal distance between two stimuli. These authors observed underestimation of horizontal distances in the affected hemifield and overestimation in the intact field (Zihl and von Cramon, 1986). The present results thus lead us to conclude that spatial neglect is not an inevitable consequence of distorted size perception. The perceptual distortion of objects in the leftward parts of visual space is not sufficient to account for the occurrence of visuospatial neglect.

Our findings contrast those of Doricchi and Angelelli's study, which revealed no perceptual distortion in patients with pure neglect or pure hemianopia (Doricchi and Angelelli, 1999). Two possible explanations may account for the discrepant results. The first is that our tasks and that employed by Doricchi and Angelelli differ in their demands. In Doricchi and Angelelli's task, patients saw a central vertical mark and a lateral dot and were asked to reproduce the horizontal distance between these two stimuli by setting another dot on the opposite side of the central mark. Thus, patients had to perceive the distance between the central mark and the lateral dot, mirror it to the opposite side, and perform a manual response which reflected their visual size perception. As Doricchi and Angelelli did not test for impairments of eye–hand coordination in their patients, a possible confounding effect cannot be excluded. Our task was purely perceptual insofar as no manual response was required. Patients reported verbally which of two stimuli was smaller or larger. Secondly, Doricchi and Angelelli actually observed a small amount of left–right asymmetry in patients with pure neglect and pure hemianopia, but they did not compare it with data for healthy controls and right-brain-damaged patients without neglect and hemianopia. Since the present control subjects performed very well in the size comparison task, it is possible that the patients in Doricchi and Angelelli's study performed significantly worse than normal subjects.

What causes the lateralized underestimation of horizontal object size and what does it mean for our understanding of spatial neglect? Our results show that it cannot be due to a general deficit in horizontal size estimation, because the patient groups did not differ from controls when matching horizontal rectangles that were arranged vertically. Thus, all patients were able to match the size of horizontal rectangles when they were presented centrally. Nor can it be due to underestimation of the distance of objects in left visual space; if this were the case, these objects would appear smaller because they are perceived as closer. But when matching the size of vertical rectangles on the two lateral halves of the screen, patients with neglect and hemianopia actually overestimated the size of the stimulus on the left half of the screen. Thus, the underestimation of the horizontal extent of the left-sided stimulus cannot be explained by an underlying misperception of the distance of objects on the left side of visual space.

Moreover, it cannot be due to impaired eye movements in hemianopic patients. Zihl and von Cramon controlled for saccadic localizations of their stimuli in their patients and found that the perceptual deficit was not related to deficient eye movements. The hemianopic patients were able to direct their eyes correctly to the target locations, although they misperceived the distance between the targets (Zihl and von Cramon, 1986).

We found that patients with pure neglect underestimated the horizontal size of the left rectangle by 5.5%. In contrast, most of these patients ignored almost all targets on the left side in the cancellation tests, i.e. at least 50% of the targets (Table 1). It is unclear how underestimation of horizontal object size by only 5.5% could lead to this dramatic deficit in cancellation tasks as well as to the gross difficulties these patients show in daily life. Nevertheless, the present results clearly confirm Milner's (Milner, 1987) and Bisiach and colleagues' assumptions of distorted size perception in patients with neglect (Bisiach *et al.*, 1994, 1996). However, our data demonstrate that patients with pure hemianopia show an even more dramatic underestimation of the left-sided rectangle relative to the patients with pure neglect (although the difference was not statistically significant). Thus, the models proposed by Milner (Milner, 1987) and by Bisiach and colleagues (Bisiach *et al.*, 1994, 1996) do not seem to account specifically for spatial neglect. Their models may turn out to be more helpful in explaining the phenomenal shrinkage of horizontal object size observed in patients with hemianopia.

Moreover, Irving-Bell and colleagues speculated whether lesions in the lower lateral aspects of Brodmann areas 18 and 19 or in the immediate vicinity of these areas caused the misperception of object size (Irving-Bell *et al.*, 1999). The brain lesions of our patients with deficient horizontal size perception showed the maximum overlap in Brodmann areas 17 and 18 (Fig. 5). Correspondingly, five out of our six patients with deficient size perception suffered from hemianopia. Spatial neglect is usually associated with lesions in the inferior parietal lobe (Vallar and Perani, 1986) and adjacent temporal lobe (Samuelsson *et al.*, 1997). Thus, the areas leading to spatial neglect on the one hand and to impaired size perception on the other hand are clearly separated, indicating that the two phenomena are not causally related.

Our study has shown that spatial neglect is accompanied by a slight misperception of horizontal object size. However, this deficit is not sufficient to explain the neglect of stimuli in what is usually a very large part of contralateral space and—even more importantly—is not specific for neglect. We found the same underestimation of the left-sided stimulus in patients with pure hemianopia without any concomitant sign of neglect, indicating that spatial neglect is not a consequence of distorted perception of size. Rather, the latter is associated with lesions of the early visual cortex.

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