

Selective horizontal dysmetropsia following prestriate lesion

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Summary

We describe a patient (P.S.) who, following a right prestriate lesion, reported that objects in the left visual field appeared distorted and smaller than those on the right. Other aspects of visual processing were remarkably unaffected. We carried out a series of size comparison tests using simple or complex stimuli and requiring different types of behavioural responses. We found that P.S. significantly underestimated the size of stimuli presented in her left visual field. When comparison tasks

involved stimuli placed along the vertical axis or in the right visual field, P.S. performed well. The vertical and horizontal components of size distortion were found to be differentially affected. We conclude that size processing may be dissociated from other aspects of visual processing, such as form or colour processing, and depends critically on part of the occipital, prestriate areas (Brodmann areas 18–19).

Keywords: size perception; micropsia; dysmetropsia; visual perception

Abbreviations: BA = Brodmann area; JND = just noticeable difference; PSE = point of subjective equality

Introduction

The size of the retinal projection of an object depends on its distance and angular position relative to the eye. As a consequence, object perception requires the image to be scaled for these parameters to compute a constant representation of the actual size. Size representation is also available for the comparison of objects of the same size, independent of their position in space. Finally, object size, together with object position and orientation in depth, are image properties that are critically important for controlling motor interactions with visual objects.

The disorder of size perception is termed dysmetropsia (also called dysmegalopsia or metamorphopsia). It can occur in different forms. Objects can appear either shrunk (micropsia) or enlarged (macropsia) compared with their actual size. Dysmetropsia can result from retinal oedema (Frisén and Frisé, 1979; Sjöstrand and Andersen, 1986) and exceptionally from lesions affecting other parts of the visual pathways (Bender and Savitsky, 1943). Transient dysmetropsia is often reported as a manifestation of epileptic seizure (Mullan and Penfield, 1959; Smith, 1980). It can also occur in migraine (Golden, 1979; Hachinski *et al.*, 1973; Klee, 1975), during infectious mononucleosis (Cooperman, 1977), as a consequence of the action of mescaline and other drugs (Iruela *et al.*, 1993), or as a psychopathological

phenomenon without evidence of neurological defect or dysfunction (Inman, 1938; Bartemeier, 1941; Schneck, 1961, 1969, 1971, 1984). Recent studies suggest that episodic dysmetropsia is not uncommon in adolescents and is probably associated with migraine (Abe *et al.*, 1989). Permanent dysmetropsia following focal cerebral lesions is rare and usually affects lateral homonymous segments of the visual field.

Selective disturbances of size processing, as demonstrated in patients with dysmetropsia, may provide evidence for independent representations of different object properties in the brain. Here we report a case of permanent left micropsia (or hemimicropsia) in a patient with a right occipital lesion following an ischaemic infarction. Our observation is in line with a few recent case reports in humans (Ebata *et al.*, 1991; Cohen *et al.*, 1994; Ceriani *et al.*, 1998) and with studies in monkeys (Desimone and Schein, 1987; Schiller and Lee, 1991) suggesting that object size is processed in the brain independently from other stimulus characteristics, at least at the extrastriate level of analysis.

We demonstrate that the vertical and horizontal components of size distortion can be differentially affected by cerebral damage. We also introduce a distinction between size processing deficits that may result in dysmetropsia and those that may accompany the neglect syndrome.

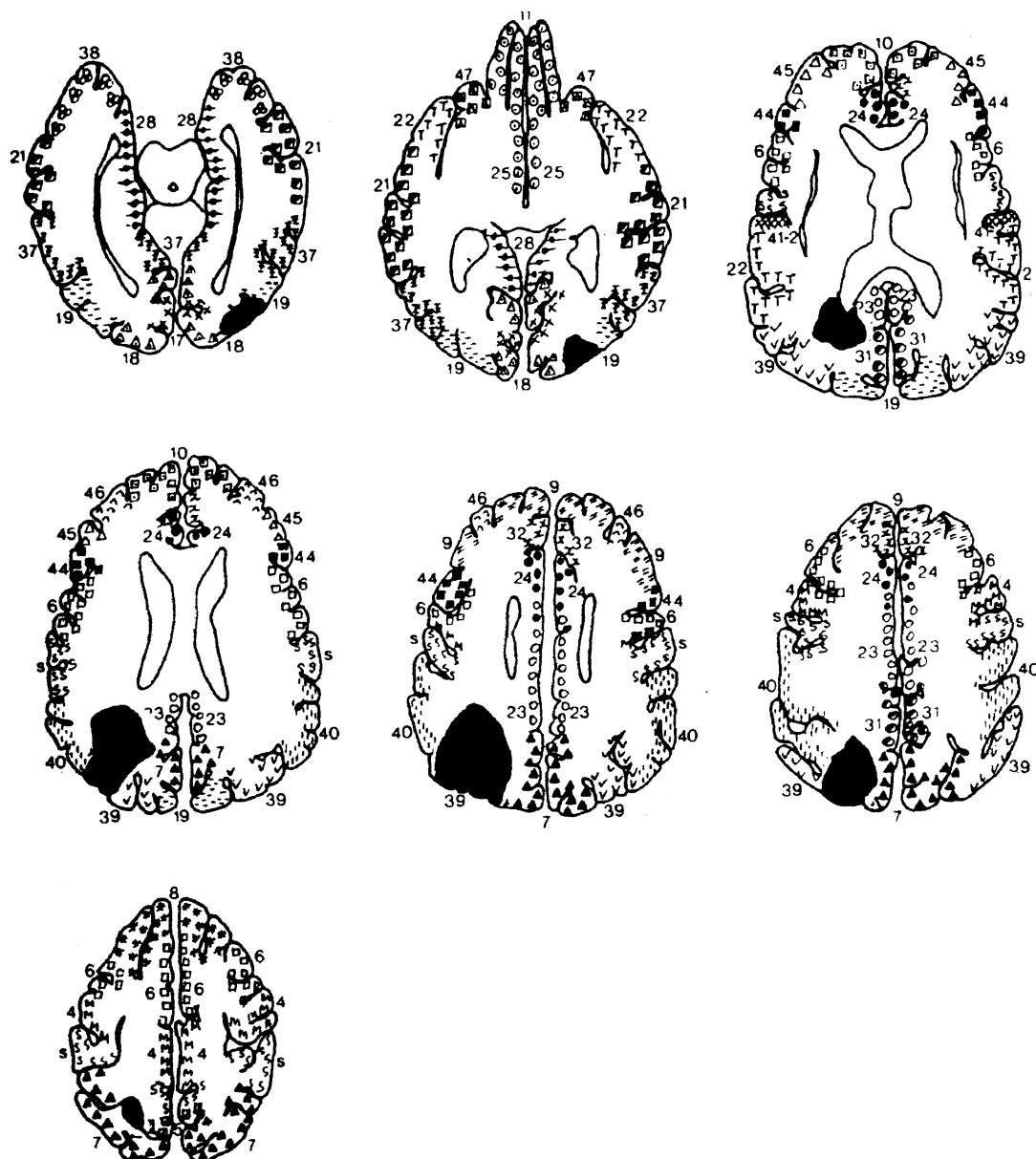


Fig. 1 MRI-based reconstruction of P.S.'s lesions using the templates from Damasio and Damasio (1989).

Case report

P.S. is a 71-year-old right-handed housewife who had 8 years of schooling. On June 27, 1995, while watching television, she noted that everything on the left appeared smaller in size, shrunk and distorted as if she 'was looking at reflections from a broken mirror.' Reading was difficult because letters appeared to overlap one another and lines of text were not properly aligned. At the beginning of the illness she reported having repeatedly spilled water when pouring it into a glass.

She was admitted to the Neurological Department of the University of Modena 2 days after the onset of the symptoms. Past medical history revealed hypertension and an ischaemic stroke in the left parieto-occipital region sustained 3 years earlier. After that stroke, she manifested a right homonymous hemianopia for few days but subsequently recovered.

On admission, general and neurological examinations were normal. The patient was able to recognize objects and to name colours, but she insisted that everything on the left side appeared distorted in its size. On specific questioning she did not refer to distorted size during dreaming or when she imagined objects with eyes closed.

Routine blood examination was within normal limits. Electrocardiogram showed a left anterior hemiblock. Colour echo-duplex scanning of the extracranial vessels was unremarkable. Computerized static perimetry was performed 3 days after onset and was also found to be normal. A second stroke was diagnosed.

One month after onset, the perceptual deficit was stable. Neuropsychological and experimental investigation of dysmetropsia was performed over a 2-month period,

Table 1 P.S.'s performance on visual perceptual tests

| | P.S.'s score | Normal subjects' score |
|---|--------------|------------------------|
| Linear length discrimination task ^a | 24/30 | >24 |
| Circle area discrimination task ^a | 13/30 | >18 |
| Figure ground discrimination test ^b | 21/30 | >20 |
| Picture naming, conventional and unconventional view ^b | 34, 04 | >33, 46 |
| Street completion test ^c | 3/14 | >5 |
| Benton's face discrimination test ^d | -0, 54 | <1, 03 |
| Age estimation ^e | 1,01 | <1,13 |

^aRiddoch *et al.* (1993); ^bWarrington and Taylor (1973); ^cDe Renzi and Spinnler (1966); ^dFaglioni *et al.* (1991); Levin *et al.* (1975); ^eDe Renzi *et al.* (1989).

beginning ~1 month after the stroke. An MRI of the brain revealed two lesions, which were reconstructed (Fig. 1) using templates from Damasio and Damasio (1989). An older lesion, on the left side, involved the inferior parietal lobule [Brodmann areas (BA) 39 and 40] and part of the superior parietal lobule (BA 5 and 6). A more recent lesion involved the lower part of the lateral aspects of the right occipital lobe, and included parts of BA 18 and 19. When related to recent functional maps based on functional MRI in humans (Tootell *et al.*, 1995, 1996; Heywood and Cowey, 1998), the presumptive location of the lesion was posterior to area MT (V5), involving ventral V4 (V4v) and part of the lateral occipital area.

The patient appeared fully oriented in time and space and was very co-operative throughout the testing period. Her spontaneous speech was fluent. She had no problems in language comprehension or in reading and writing. Verbal (Novelli *et al.*, 1986; Orsini *et al.*, 1987), spatial (Spinnler and Tognoni, 1987) and visual (Faglioni *et al.*, 1991) memory were investigated extensively and found to be normal.

She performed flawlessly in naming objects (De Renzi *et al.*, 1987) and colours (Benton, 1967). Colour identification (Benton, 1967) was also quite good. Her performance in recognizing famous faces was normal. She performed well in the test of Talland (1958), which requires the subject to point to the steepest member of a pair of arches. However, she was impaired in copying simple drawings and in several perceptual tasks involving length discrimination (Riddoch and Humphreys, 1993), line orientation (Benton *et al.*, 1975), etc. (for details see Table 1). In a line cancellation task (Albert, 1973) and line bisection test there was no evidence of unilateral visuospatial neglect. In Bell's test (Gauthier *et al.*, 1989), a task involving searching for a small bell in a random array of similar pictures, she neglected a few items both on the right and on the left side. We also examined whether P.S. had visuospatial extinction. On each trial, one stimulus, in either the left or the right hemifield, or two simultaneous stimuli were displayed briefly (25 ms) on a computer screen that was ~45 cm from the patient. Stimuli were black filled circles (0.8° of visual angle) presented at a 5° visual angle from a central fixation cross. On single-

stimulus trials, P.S. omitted 3 out of 20 stimuli on the right side and was errorless on the left side. On double-stimulus trials, she failed to report the right-sided stimulus in 6 out of 20 trials.

To test stereoacuity we administered the Titmus test (Titmus Optical Co., Petersburg, Va., USA). The test consists of horizontally offset stimuli reflecting polarized light in orthogonal directions. With appropriately polarized lenses, the subject can view the stimulus (a circle) on a closer plane with respect to the background. Target stimuli have graded disparities. The patient's performance in this test fell completely within normal limits.

To evaluate depth perception from multiple cues we devised a task requiring the patient to judge the relative distances of two sticks of different height (5 and 5.5 cm). The test consisted of a wooden box (4.5 cm high × 7.5 cm wide × 10 cm thick) presented in front of the patient at eye level, at a distance of ~150 cm. The box had nine holes on its upper side arranged in three rows and three columns. There was a distance of 1 cm between rows and 2 cm between columns. In each trial the experimenter placed the sticks in holes of two different columns, either in the same or different rows. P.S. was required to indicate which of the two sticks was nearer in a block of 10 trials, and which of the two sticks was further in a separate block of 10 trials. When the two sticks were in different rows, P.S. was always correct. When the two sticks were at the same distance from the patient (same row), and she was prompted to indicate either the closer or farther stick; she did so at random, thus demonstrating the absence of bias in depth perception.

To investigate the origin of the patient's visual complaints we administered the Size Matching Task included in the Birmingham Object Recognition Battery (Riddoch and Humphreys, 1993). Version A of this task consists of 30 pairs of circles, aligned horizontally. Half of the pairs are of the same size, and the remaining half are of different sizes. The subject's task was simply to say whether the two circles were or were not identical. P.S. scored only 13 out of 30 correct (mean score for controls: 23 out of 30). During testing P.S. showed a clear trend towards responding that the right circle was larger when they were in fact identical. Accordingly, she assumed that they were identical when the left circle was slightly larger than the right one. We also administered version B of the same task, which requires the subject to match vertically aligned pairs of circles. P.S. scored 30 out of 30 correct at this task, thus showing that she had trouble with size-matching only when stimuli were aligned along the horizontal axis. These findings prompted us to run further experimental investigations as reported below.

Experimental investigation

Experiment 1 was carried out on an IBM 486 PC equipped with custom software. Experiments 2, 5, 6, 7 and 8 were carried out on a Power Macintosh 100/66 microcomputer equipped with a 21-inch Apple colour monitor, providing

1280 × 1024 pixel resolution at a vertical refresh rate of 75 Hz. We used Superlab™ v. 1.5.5 (Cedrus Corporation, Phoenix, Ariz., USA) for creating and running the experiments. P.S. was seated in front of the screen. Viewing distance was ~45 cm.

Data for Experiments 3 and 4 were collected with paper and pencil. Experiments 1, 5, 6 and 8 were also administered to six normal control subjects (mean age 68.5 years, range 62–75; mean educational level 6.8 years, range 5–13 years). A different group of six normal subjects served as controls for Experiment 8 (mean age 65.3 years, range 46–77; mean educational level 9.1 years, range 5–16 years).

The patient and the normal controls were fully informed of the purpose of the study and they gave informed consent to participation.

Experiment 1

Experiment 1 was aimed at quantifying P.S.'s size perception of objects placed along the horizontal and vertical meridians. For each trial, a pair of empty circles was presented on the computer screen, with one circle larger than the other. The patient was free to move her gaze. Ten pairs were aligned horizontally and ten were aligned vertically. In half of the horizontal trials, the larger circle was on the right (or up for the vertical trials) whereas in the remaining half it was on the left (or down). The diameter of the smaller circle was 35 mm, whereas the larger one had a diameter of 50 mm. The centres of the two circles were 110 mm apart. P.S. was required to enlarge the smaller circle by pressing the spacebar of the keyboard until the sizes of the two circles were identical.

Results

When the circles were aligned horizontally, P.S. enlarged the left one more than control subjects (mean for P.S., 54.4 mm; range for normal controls, 47.4–50.4 mm) and the right one less than control subjects (mean for P.S., 43.2 mm; range for normal subjects, 46.6–49.8). When circles were vertically aligned, P.S. performed almost as accurately as normal subjects (upper circle: mean for P.S., 48.2 mm; range for normal controls, 46.4–49.8 mm; bottom circle: mean for P.S., 47.4 mm; range for normal controls, 48.8–51).

Experiment 2

This experiment assessed whether micropsia for stimuli appearing on the left side was also present with more complex configural patterns. For this purpose we used a line drawing of a dog taken from the set of pictures by Snodgrass and Vanderwart (1980). The original drawing was 7.3 × 5.2 cm. We enlarged it by 5, 10, 15, 20 and 25% of its original size. We then assembled horizontally aligned pairs of stimuli consisting of either two original drawings or the original drawing and its enlarged version. The original drawing was

on either the left or the right of a central fixation point. Each pair of stimuli was presented five times, giving a total of 55 trials. The task was presented under two stimulation conditions: with stimuli flashed for 800 ms and with stimuli presented for an unlimited time. The subject was free to move her gaze. She was told that the two drawings were always of different size and was requested to point to the 'larger dog' even if they appeared to be of the same size.

Results

When the pictures of the dog were of the same size, the patient judged the left dog to be smaller than the right one 5 out of 5 times, both at 800 ms and at unlimited exposure time. When the left drawing was 5, 10 and 15% larger, she judged it to be smaller 4 out of 5, 2 out of 5 and 3 out of 5 times, respectively, at 800 ms exposure. With unlimited exposure, her errors were 2 out of 5, 1 out of 5 and 0 out of 5, respectively. Whenever the left stimulus was 20 or 25% larger, she always performed correctly. As expected, she also made no errors in all the trials where the dog on the left was smaller. In conclusion, even with complex configural patterns, the patient tended to judge the left stimulus smaller than the right, both when they were identical and when the left was up to 15% larger.

Experiment 3

The aim of this experiment was to determine whether perceptual size distortion also occurred with symmetrical stimuli. For this purpose we used a line drawing of a butterfly, taken from the collection of Snodgrass and Vanderwart (1980). We printed three copies for each of the following three exemplars of the butterfly, which only differed in dimensions: 5 × 3 cm (small), 6 × 4 cm (medium), 7 × 5 cm (large). We then cut the butterflies along their line of symmetry and assembled each half of the drawing with the opposite halves of the remaining two drawings. We thus obtained nine butterflies useful for the experiment: three of them consisted of two identical halves (small–small, medium–medium, large–large) and corresponded to the original drawings. The remaining six butterflies had two halves of different size joined together (small–medium, small–large, medium–large, medium–small, large–small, large–medium) and were asymmetrical, with the larger half on either the right or the left side. In each trial, we presented the subject a butterfly and asked her to correct with a pencil either the larger or the smaller part of the drawing, in order to make it look symmetrical. Each stimulus was positioned on the desk so that the butterfly's midpoint was aligned with the central sagittal plane of the patient's trunk and head.

Results

The patient's corrections were rather sketchy (see Fig. 2 for an example). To evaluate the size of butterflies formally (as

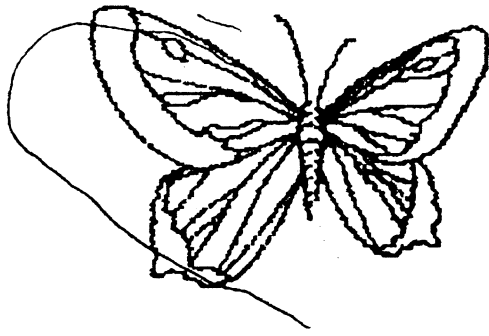


Fig. 2 One example of P.S.'s performance in Experiment 3. The patient was asked to fill in with a pencil one half of the butterfly to make it a symmetrical figure.

corrected by P.S. in order to make them symmetrical), we first connected each end of the patient's drawings with the closest point lying on the butterfly's line of symmetry. Then we scanned the resulting drawings and computed the areas of both the original and the corrected half of the butterfly by means of NIH Image v. 1.49 software (Wayne Rasband, National Institutes of Health, Bethesda, Md., USA). In eight out of nine trials, P.S. enlarged the left half of the drawing, and only in one out of nine trials did the left half of the drawing turn out to be larger than the right one. On average, the area of the left half of the drawing (1187 mm²) was larger than that of the right half (894 mm²; $t(8) = 3.246$; $P = 0.01$). Based on performance on this task, we can conclude that to perceive the left half as large as the right half, P.S. enlarged it by ~25%.

Experiment 4

In the previous experiment P.S. was asked to provide a measure of her perceptual distortion by drawing her corrections over both symmetrical and asymmetrical patterns. The results were highly suggestive of perceptual impairment. However, it was impossible to determine formally whether the patient's sketches reflected perceptual or drawing inaccuracies. For this reason we devised an experiment to check the distorted size perception with a comparison paradigm. Furthermore, we wanted to test whether or not dysmetropsia also involved faces, since in a recent case report (Ebata *et al.*, 1991) this perceptual disorder was apparently limited to this kind of object. For this purpose we selected the most symmetrical face from a set of 20 black and white photographs of famous people. The photograph chosen showed the face of Farah Diba, the former princess of Iran. We divided it into two halves along the line of symmetry and enlarged both the right and the left half by 5, 10 and 15% linearly by means of a photocopier. The original size of the image of the face was 10 × 14 cm. The enlarged hemifaces were then assembled with the opposite original hemiface and presented in random order with the original photograph for an unlimited exposure time. The subject sat at a table at an eye distance of ~50 cm from the photograph.

The midpoint of the figure was aligned with the subject's mid-sagittal plane. The subject's task was to indicate the larger hemiface.

Results

The left hemiface was always judged to be smaller when the two halves were identical in size and when the left half was 5% larger than the right. The same was true in one out of four trials when the left half was 10% larger. There were no errors when the left hemiface was 15% larger and whenever the right hemiface was larger. It was concluded that the size distortion with symmetrical stimuli was of perceptual origin. It also occurred with faces presented for an unlimited time.

Experiment 5

The processing size of horizontally aligned stimuli can be affected both by size distortion (i.e. a specific bias in indicating one stimulus larger or smaller than the other) and by size discrimination accuracy (i.e. the ability to detect subtle size differences). The aim of this experiment was to investigate separately size distortion and size discrimination accuracy. We also wanted to compare separately the vertical and horizontal components of size distortion.

For this purpose we devised three tasks: horizontal line discrimination, vertical line discrimination and circle discrimination. On each trial, we presented for an unlimited time a pair of horizontally aligned stimuli: vertical lines, horizontal lines or circles. The centres of the two circles were 8 cm apart and the distance between the midlines of the two horizontal lines was 8 cm. The distance between the two vertical lines was 6 cm. One stimulus of each pair was constant in its length or diameter (4 cm). The length (or diameter) of the other member of the pair was increased by 0, 2, 4, 6, 8, 10, 12, 18, 24, 30 or 36 mm. In half of the trials the larger stimulus was presented on the left and in the other half it was on the right. Each pair was presented 10 times in random order. Subjects were informed that the two stimuli were never identical. They were asked to indicate the larger member of each pair.

Results

We first plotted the proportion of trials in which the left stimulus was judged to be larger as a function of the difference between the left-right length (or diameter) (Fig. 3). Then, the proportions of 'left larger' responses [$P(L)$] were analysed by iterative least-squares fitting to an unbiased exponential logistic regression for the left-right difference (D). For each subject and each task we computed the function:

$$P(L) = \frac{e^{(\beta_0 + \beta_1 D)}}{1 + e^{(\beta_0 + \beta_1 D)}}$$

Then, based on each individual function, we obtained (i)

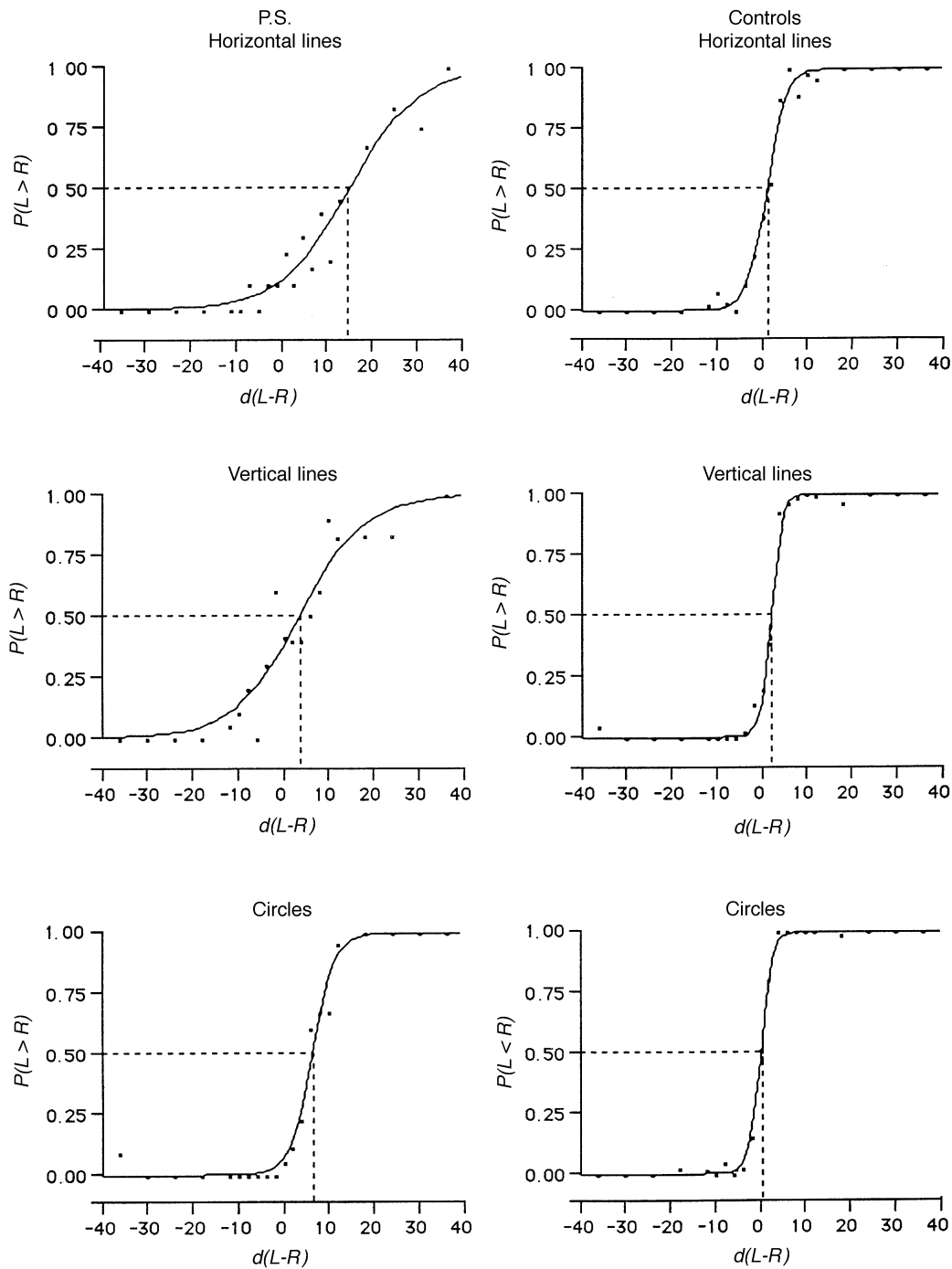


Fig. 3 Experiment 5. Graphic representation of the performance of P.S. (left) and normal controls (right) in matching horizontal lines, vertical lines and circles. The ordinate represents the proportion of trials (P) in which the left-sided stimulus was overestimated as a function of the left-right size difference (in millimetres). Each data point for P.S. is averaged across 210 trials. Each data point for normal controls is averaged across six subjects and 210 trials. Negative values indicate a stimulus smaller on the left; positive numbers indicate a stimulus larger on the left. $d(L - R)$ = left-right size difference.

the point of subjective equality, i.e. the left-right difference classified as 'left larger' on 50% of the trials, and (ii) the just noticeable difference (JND), i.e. half the difference of stimulus length (or diameter) classified as 'left larger' on 75% of trials and that classified as 'left larger' on 25% of trials.

The point of subjective equality (PSE) and the JND obtained by P.S. and by six normal controls are reported in Table 2. Data show that the size discrimination accuracy of P.S. (JND) was worst with horizontal and vertical lines and much better with circles. However, the systematic bias in

Table 2 Experiment 5

| | Horizontal lines | Vertical lines | Circles |
|---|------------------|----------------|---------------|
| (A) Point of subjective equality | | | |
| P.S. | +14.385 | +3.769 | +6.384 |
| Mean for normal subjects | +0.731 | +1.957 | +0.004 |
| Range for normal subjects | -2.186/+1.936 | +0.077/+2.69 | -1.377/+1.329 |
| (B) Just noticeable difference | | | |
| P.S. | +8.451 | +8.451 | +2.719 |
| Mean for normal subjects | +2.434 | +1.262 | +1.277 |
| Range for normal subjects | +1.772/+3.533 | +0.904/+1.894 | +0.408/+1.616 |

In **A** numbers represent the extent (in millimetres) by which the left stimulus had to be larger than the right one to appear of equal size. In **B**, the values given are in millimetres. See text for details.

indicating the right stimulus larger than the left one, as measured by the PSE, was much more evident with horizontal lines than with vertical lines.

Experiment 6

The aim of this experiment was to study the influence of the spatial location of stimuli on P.S.'s size distortion. Each trial began with a fixation cross presented at the centre of the display. When the subject was ready the experimenter triggered stimulus presentation. Stimuli were pairs of horizontally aligned circles presented for 250 ms. The centres of the two circles were 6 cm apart. The midpoint of the distance between them was presented either at the centre of the computer screen or 5 cm to the right or left of the centre. The diameter of one of the two circles was 3 cm. The diameter of the other one was greater than this by 0, 6, 12, 18 or 24 mm. A total of 324 pairs of circles was presented in a balanced random order at the different spatial positions. Subjects were informed that the two stimuli were never identical, and they were asked to indicate the larger member of each pair.

Results

Figure 4 shows the proportion of trials in which the left-sided stimulus was overestimated as a function of left-right size difference. Data were analysed as in Experiment 5. As shown by JND values, P.S. was as accurate as normal subjects in discriminating size at the centre of the visual field. Also, she appeared equally impaired in both hemifields (Table 3B). PSE values demonstrate that P.S. had a systematic bias towards judging the left circle smaller than the right one when both stimuli appeared in the left visual field and when the midline of their distance was presented at the centre of the visual field. When both stimuli were presented in the right visual field, PSE was within the normal range, i.e. there was no dysmetropsia (Table 3A).

These results confirmed that size discrimination accuracy (as evaluated by JND) and size perceptual distortion

(measured by PSE) are independent. They also showed that dysmetropsia only occurred when either one or both stimuli in our comparison task fell in the left visual field.

Experiment 7

Previous experiments involved comparison of two stimuli displayed simultaneously at two sides of a central point of fixation. However, with this kind of task retinal and spatial coordinates are confounded, and it remained unclear in which system of coordinates P.S.'s deficit operated. To remedy this problem, we presented one stimulus at a time, either to the left or to the right of fixation. P.S. was asked to examine a horizontal line in central vision without time limitation. When satisfied with her inspection, she pressed the space bar of the keyboard and a line for comparison was presented on the other side of fixation. Again, there was no time constraint for examining the second line. The patient's task was to compare the length of the second stimulus with that of the previous one. Thus, although the two lines were presented in different halves of space, as defined by head- or trunk-centred coordinates, they were projected to the same part of the retina. Consequently, if P.S.'s micropsia operated in retinal coordinates, then no deficit would be expected in this condition.

One stimulus of each pair was constant in length (4 cm). The length of the other member of the pair was greater than this by 0, 6, 12, 18, 24, 30 or 36 mm. On half of the trials the longer line was presented towards the left side, whilst on the other half the longer line was to the right. The side of the first presentation was also randomized across trials. P.S. was informed that the two lines were never identical. There were two separate blocks of trials. In one block of trials, the patient was asked to indicate the longer line and in the second block she was required to indicate the shorter line. Within a block, each pair was presented four times, giving a total of 56 trials administered in random order.

Results

The proportion of trials in which the left stimulus was judged to be larger was analysed as a function of the

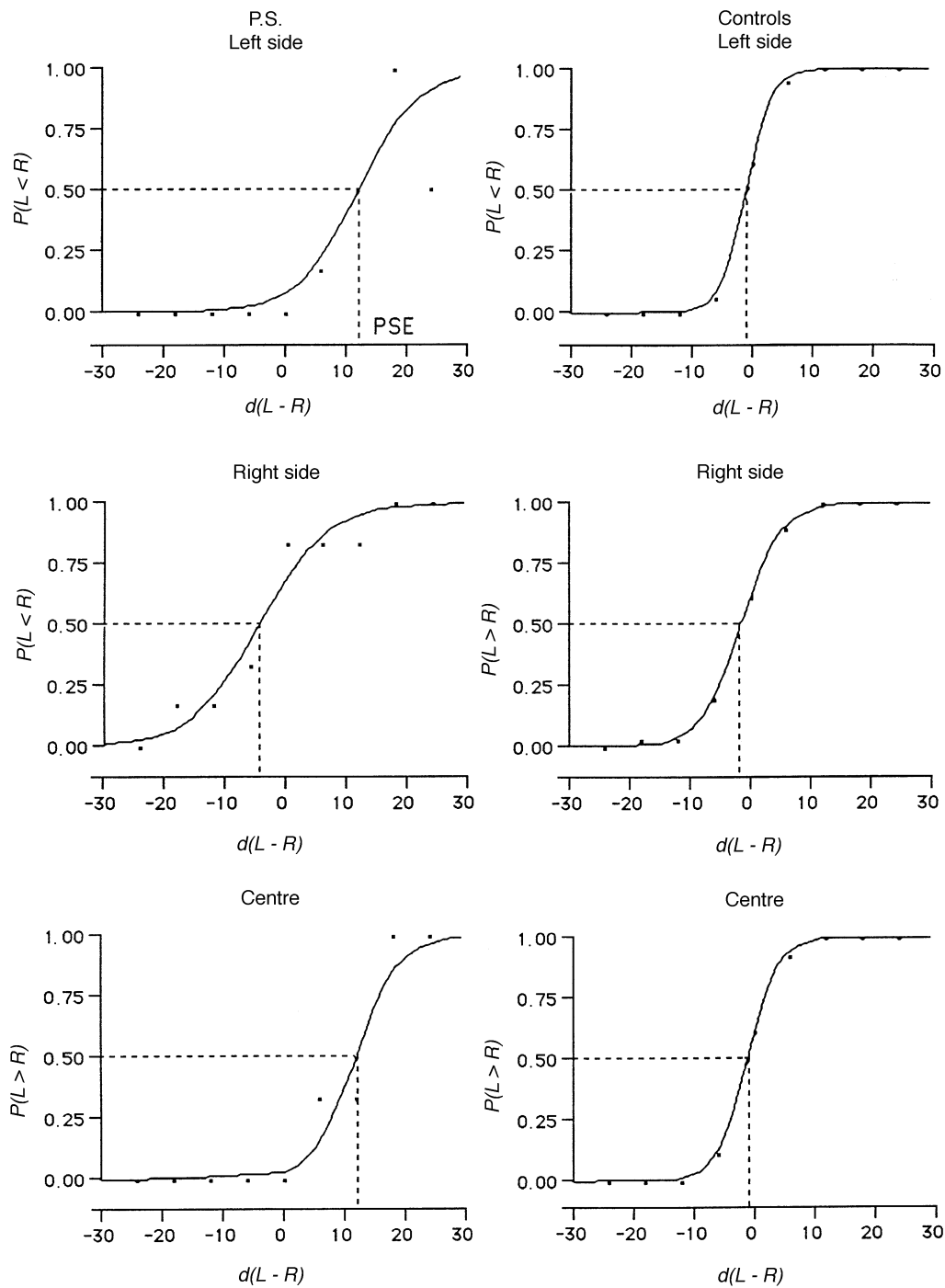


Fig. 4 Experiment 6. Graphic representation of the performance of P.S. (left) and normal controls (right) in matching circles presented on the right and left sides and in the centre. The ordinate represents the proportion of trials (P) in which the left-sided stimulus was overestimated. The abscissa represents the left–right size difference (in millimetres). Each data point for P.S. is averaged across 108 trials. Each data point for normal controls is averaged across six subjects and 108 trials. Negative values indicate a stimulus smaller on the left; positive numbers indicate a stimulus larger on the left; $d(L - R)$ = left–right size difference.

difference between the left–right length, as in Experiment 5. We therefore calculated the PSE and JND values. The PSE value was zero, thus demonstrating that, when the patient inspected each stimulus in central vision, there was no bias in reporting the right stimulus as larger than the left.

In the present experiment the JND value obtained by P.S. was <1 mm (0.68 mm), whereas it was 7.8 mm in Experiment 5. In other words, the size discrimination accuracy of the patient was much better when she was free to move her gaze. We conclude that P.S.’s left-sided

Table 3 Experiment 6

| | Right | Left | Centre |
|---|---------------|--------------|---------------|
| (A) Point of subjective equality | | | |
| P.S. | -4.302 | +12.4 | +12.048 |
| Mean for normal subjects | -1.462 | -1.057 | -1.13 |
| Range for normal subjects | -7.794/+5.743 | -5.739/+0.41 | -3.77/0 |
| (B) Just noticeable difference | | | |
| P.S. | +6.036 | +5.493 | +3.814 |
| Mean for normal subjects | +2.5 | +1.02 | +1.94 |
| Range for normal subjects | +0.142/+4.803 | +0.287/+2.87 | +0.265/+4.782 |

In **A**, numbers represent the extent (in millimetres) by which the leftmost stimulus had to be larger than the rightmost one to appear of equal size. In **B**, the values given are in millimetres. See text for details.

micropsia operated in retinal rather than body-centred coordinates.

Experiment 8

The results of the experiments conducted thus far indicate that P.S. perceived objects projected on her left hemifield as smaller along their horizontal axis. This caused the distortion she was complaining of. This experiment investigated whether P.S.'s deficit was a consequence of a generalized distortion of the left visual field along the horizontal meridian or whether it selectively involved the process of assigning the size to a left-sided object. To this end, we asked P.S. and six control subjects to compare the horizontal distance between left- and right-sided targets from the centre of the display.

At the beginning of each trial, P.S. was required to gaze at a cross located at the centre of the screen. When fixation was achieved, the experimenter triggered the stimulus. Stimuli were two vertical lines 2 cm long, presented along the horizontal meridian, one at each side of fixation. One stimulus was at a distance of 1 cm from the fixation point, whereas the other was at a distance 0, 1, 4, 8 or 15 mm greater than this. In half of the trials the farther stimulus was on the left and in the other half on the right. Subjects were informed that the two stimuli were never at the same distance. In two separate blocks of trials they were asked to indicate the farther or nearer stimulus. Within a block, each pair was presented nine times, giving a total of 90 trials administered in random order.

Results

We plotted the proportion of trials in which the left stimulus was judged to be nearer as a function of the difference between the left-right distance. The proportion of 'left nearer' responses [$P(L)$] was then analysed by iterative least-squares fitting to an unbiased logistic regression for the left-right difference (D).

P.S.'s PSE was 2.45 mm. That is to say, P.S. perceived the two lines at the same distance from the centre when the left stimulus was 2.45 mm farther than the right stimulus. The

mean value of the normal subjects' PSE was 1.61 mm (range, 1.26–2.49 mm). As a consequence, the patient's PSE can be considered within the normal range. Also, P.S.'s distance discrimination accuracy (JND = 0.14 mm) was within the range of the normal controls (0.09–1.69 mm).

Discussion

We have documented the case of a patient, P.S., who showed an impairment in visual size perception following a right occipital stroke. Her disorder, known in the neurological literature as hemimicropsia, consisted in a reduction of the apparent size of objects presented in the left hemifield compared with objects presented in the right hemifield.

The patient was aware of her visual difficulty and reported it in great detail. Left hemimicropsia reliably occurred across a variety of left-right size comparison tasks, with both simple and complex stimuli, and it was worsened by reducing exposure time. In Experiments 2, 4, 5 and 6, P.S. was required to indicate the larger stimulus. However, in Experiment 1 we excluded any response bias by asking the patient to look for the smaller stimulus and to make it as large as the paired one. Also, micropsia was absent when objects were vertically aligned, thus ruling out a failure in perceptual matching *per se* (Experiment 1).

Other aspects of visual processing were remarkably intact. P.S. was neither alexic nor achromatopsic. She promptly and accurately recognized objects and faces presented in different parts of the visual field. She was as accurate as normal subjects in Benton's face-matching test, and she did relatively well in discriminating arches of different steepness as required by the Talland test. We also found that her perceptual bias in judging the size of a stimulus was partly independent of her accuracy in size discrimination (Experiments 5 and 6). However, she fell short of normal scores on figure copying and on Benton's line orientation matching task, which suggests that orientation processing was also impaired. Note, however that P.S.'s abnormal performance in these tasks may have been affected by her misperception of size. For instance, a differential size perception impairment along the horizontal

and vertical axes might cause a distortion in the perceived orientation of a tilted stimulus.

Micropsia emerged only for objects displayed in the hemifield contralateral to the prestriate lesion (Experiment 6). Although in our case the left hemifield was involved, size distortion restricted to the right hemifield has also been described (Thiébaud and Matavul, 1949; Cohen *et al.*, 1994). This finding suggests that the prestriate cortex contributes to size processing only for contralateral objects. In this regard it might have been useful to test size comparisons of two vertically separated circles presented in a single hemifield. However, unfortunately the patient was not available for further testing.

P.S.'s size perception deficit was coded in retinal and not in spatial coordinates, as demonstrated by her underestimation of left-sided stimuli in perceptual matching tasks as opposed to her normal performance when she was required to inspect them in central vision (Experiment 7). Most importantly, contrary to normal subjects (who performed better in matching horizontal than in matching vertical lines), we found that P.S.'s size distortion was greater for horizontal than vertical lines (Experiment 5). Consequently, we argue not only that size perception can be dissociated from other aspects of visual processing such as form and colour, but also that the perception of the horizontal and vertical dimensions of a visual object depends on separate neural mechanisms which may be selectively impaired after a focal cortical lesion.

Although P.S. underestimated the horizontal extent of visual objects in the left hemifield, she performed normally in judging the horizontal distance of a left stimulus from the centre of the screen (Experiment 8). This result demonstrates that size distortion was not simply due to a distortion of the visual field along the horizontal axis, but rather it involved the process of assigning a size to an object.

Precise anatomical details on the locus of the lesion responsible for dysmetropsia are lacking in most of the reported cases. An overview of the literature revealed that the deficit is much more common after damage of the visual association cortex (Wilson, 1916; Bender and Teuber, 1947, 1948; Brégeat *et al.*, 1947; Thiébaud and Matavul, 1949). For instance, Brégeat *et al.* (1947) reported a patient who complained of a right hemimacropsia immediately after the excision of a tumour involving the inferior portion of the left occipital lobe (parastriate area 19). Bender and Teuber (1947) described the case of a patient with altered size perception occurring after a right occipital lesion. As a rule, their patient experienced a micropsia for objects presented in the (left) contralesional field but, under certain circumstances, the disorder could reverse to left macropsia. More recently, Cohen *et al.* (1994) described two cases of hemimicropsia resulting from a lesion affecting the lower part of areas 18 and 19 and the underlying white matter. In a patient described by Ceriani *et al.* (1998), who complained of seeing objects smaller than they were in the whole visual field, the lesion apparently involved the right temporoparietal cortical junction and the occipital white matter. In the case

reported by Ebata *et al.* (1991), left micropsia followed a lesion of the right posterior part of the cingulate cortex, just behind the splenium of the corpus callosum. Note, however, that this patient's deficit, which apparently involved only faces, was not evaluated in any formal way.

P.S. had two lesions: an older one on the left side, including the inferoparietal lobule and part of the superior parietal lobule, and a more recent one encroaching on the lower part of the lateral aspect of the right occipital lobe, which could include area V4 and the lateral occipital area, as defined by functional MRI studies in humans (Tootell *et al.*, 1995, 1996; Heywood and Cowey, 1998).

We argue that her deficit was the consequence of damage to the right prestriate cortex. P.S. did not complain of any perceptual abnormality in the visual field following the parietal infarct, whereas she did so acutely after the lesion in the occipital lobe. Furthermore, clinical and behavioural data show that P.S.'s dysmetropsia was lateralized and involved only objects displayed in the left hemifield. Finally, P.S.'s occipital lesion involved anatomical areas which closely matched those damaged in the cases of hemimicropsia reported by Cohen *et al.* (1994). Interestingly, in a patient with recurrent episodes of hemimicropsia (Kassubeck *et al.*, 1998) the misperception disappeared after removal of a cavernous angioma located in the right prestriate cortex (BA 19, adjacent to BA 37).

In conclusion, we maintain that lesions causing dysmetropsia involve the inferior portion of the right parastriate area but spare both the calcarine region and the geniculostriate projections. Indeed, if the lesion affected the two latter structures, patients would manifest hemianopic deficits which would prevent the expression of a disordered size perception. The idea that the prestriate visual cortex may play a crucial role in the perception of an object's size and shape also rests on a series of experimental studies in non-human primates. Single-cell recording demonstrates that neurons in area V4, a possible homologue of area 18 in man, selectively respond to bars of a particular length and width presented within a large receptive field (Desimone and Schein, 1987). Furthermore, the cell selectivity for bars of a certain size is maintained over shifts of the stimulus location. This generalization of cell response over different spatial positions may contribute to the perceptual equivalence of objects, regardless of their projections on the retina. Moreover, lesions of area V4 in macaques result in a wide range of perceptual deficits, including significant losses in size perception (Schiller and Lee, 1991). Many issues remain to be addressed in further studies. For example, we cannot explain why focal damage of the prestriate areas results in micropsia in some patients whereas in others it produces (more rarely) macropsia. Exact mapping of the visual areas disrupted by the lesion may provide some clues to the solution of this problem.

Neuropsychological evidence in humans suggests that size perception may be mediated not only by prestriate lesions but also by a system located in the inferior parietal lobule.

Patients with lesions of this region ignore objects presented on the contralesional side of space (visuospatial neglect) or, when they acknowledge their presence, they process them in an abnormal way. Unilateral neglect is often conceived as a spatial attentional or representational disorder which leaves the primary sensory mechanism for the affected side of space intact. Recently, Milner and Harvey (1995), using a psychophysical comparison task (similar to those employed here in Experiments 5 and 6), found that neglect patients significantly underestimate the horizontal extent of stimuli presented on the contralesional half of their egocentric space. This finding closely parallels the results we obtained with P.S. However, P.S. did not show any evidence of left spatial neglect across a wide range of tests. On the contrary, when two stimuli were briefly displayed simultaneously on both sides of fixation, she showed a mild tendency to miss the right one (probably due to the older left parietal lesion). Moreover, patients with disorders of spatial attention show a systematic bias in locating contralesional objects towards the ipsilesional side, whereas P.S. had no such bias (Experiment 8). Finally, P.S. spontaneously complained that objects in her left visual field appeared smaller and distorted, whereas neglect patients are not aware of their abnormal size perception. We argue, therefore, that P.S.'s perceptual size deficit cannot be interpreted as due to an attentional bias against the left hemifield.

We propose that size perceptual distortions may stem from two different causes: (i) a deficit in the ability to judge spatial relationships both between and within objects, which might be expected after a parietal lesion; (ii) a failure at an early stage of the processing of visual object features which can follow a prestriate lesion. Stimulus size might be analysed differently by the parietal and the prestriate cortex. The parietal coding system may be critical for processing size information for the purpose of visuomotor control (Sakata *et al.*, 1996), whereas the prestriate system may compute size in order to maintain a constant representation of objects across variations of distance and position. For unknown reasons, damaging part of this latter system can cause shrinking more often than enlargement of the perceived size of objects. Such a defective perception can occur with little, if any, impairment of size discrimination ability.

Acknowledgements

We wish to thank Edoardo Bisiach and Jordan Grafman for their comments on an early version of the paper, and the referees for criticism that prompted us to devise Experiments 7 and 8. We also wish to thank John Pradelli for revising the English text and Paolo Maggi for his constant support. Part of the work described in this paper was presented at the European Workshop in Cognitive Neuropsychology, Bressanone, 1997.

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Received July 24, 1998. Revised September 16, 1998.

Accepted October 5, 1998