Patients with visual neglect show deficits in horizontal size perception in their neglected hemispace, as previously reported. The present study examined whether this size distortion can be modulated by visual background motion to the left or right while the patient performs a visual size judgment task. Six neglect patients and six normal subjects were investigated with a psychophysical size judgment task. All neglect patients showed a significant perceptual underestimation of horizontal bars in their left hemispace expressed as an overestimation of horizontal object size in the baseline (no motion) condition. Slow visual motion of background stimuli towards the right, ipsilesional side, aggravated the deficit slightly, but not significantly, whereas leftward background motion completely normalized the size distortion in four cases or even led to an overcompensation in two cases. This facilitatory effect was specific as it was obvious for the constant errors in the size judgments, but not in their accuracy as reflected by unchanged difference thresholds. These results suggest that coherent background motion restores temporarily the disturbed perception and representation of horizontal object size in spatial neglect.

Key words: Brain damage; Rehabilitation; Spatial perception; Visual motion; Visual neglect

Introduction

Patients with left spatial neglect typically show a rightward deviation in horizontal line bisection tasks [1] and may exert profound deviations in judging the horizontal spatial extent of objects (e.g. bars or rectangles) in their neglected hemispace [2,3]. Milner and Harvey [1] have termed this phenomenon 'size distortion' and argued that it may be viewed as the manifestation of a spatial, horizontal compression of visual stimuli in the neglected hemispace. Several manoeuvres have been shown to modulate neglect in line bisection or line extension tasks. Fast optokinetic stimulation towards the neglected hemispace [4], the display of apparent motion at the left end of the line [5] and slow horizontal background motion to the left [6] have been shown to reduce the horizontal line bisection error probably by allocating selective attention to stimuli in the neglected space sector [6]. In contrast, Bisiach and colleagues [7] showed that leftward motion stimulation aggravated the spatial error of neglect patients in a line extension task. Hence, moving background stimuli may either improve or aggravate visual performance in neglect patients, depending on the nature of the task. The present study sought to combine a horizontal size judgment task with the technique of slow visual background motion to test whether left- or rightward background motion can modulate the horizontal size distortion error in patients with left visual neglect.

Materials and Methods

Subjects: Six patients (four male, two female, mean age 53 years, range 35–72) with right hemispheric lesions (time post-onset 1–5 months), documented by CT/MRI scans, and left-sided spatial neglect (severe in five cases, moderate in one) as documented by conventional tests (line bisection, cancellation, drawing) were tested and compared with six age-matched, normal subjects (three male, three female; mean age 48 years, range 42–73; see Table 1).

Neglect tests and visual perimetry: Four conventional neglect tests were performed: horizontal line bisection of a 20 × 1 cm black line on a white sheet of paper; number cancellation (30 targets among 150 distractors, presented on a 29.7 × 21 cm large white
paper), drawing of a clock face and a standardized reading test of 180 words. Neglect was diagnosed when the truncation midline in bisection deviated more than 5 mm to the ipsilesional side, when more than three targets were omitted on the left side of the number cancellation task, or when numerals were omitted or misplaced on the left side of the clock face test, or when the patient made more than two omissions or substitutions in the reading test. In addition, binocular visual fields [8] were mapped perimetrically with a Goldmann perimeter or with confrontation perimetry in two cases. The type of scotoma and the visual field sparing on the left horizontal meridian are given in Table 1. In the two cases without perimetry the visual field sparing was estimated with finger perimetry.

**Visual size estimation task:** A horizontal bar of 6 × 1 cm length (the standard stimulus) was presented on the right side of a computer monitor. On the left side a shorter stimulus (3 × 1 cm, the target stimulus) was presented which was to be adjusted to the same horizontal length as the target. The subject was instructed to indicate verbally how the target had to be adjusted by the examiner to show the same horizontal size (vertical size was always 1 cm, see Fig. 1). After this was established the examiner elongated the target continuously in steps of 0.5 mm asking if the target still had the same length as the standard stimulus. A trial was finished when the subject indicated that the target was too long. With this method constant errors and different thresholds were calculated. Constant errors denote the difference between the judged length of the target and the standard stimulus, while the difference threshold is defined as the half of the interval during which the patient judges both bars as having the same length [9].

**Global background motion:** Two stimulation conditions with linear, horizontal background motion (left or right) were established by displaying 150 yellow squares (0.8 cm) on the dark background of a 17" computer monitor. All stimuli moved coherently in one direction (left or right) at a constant speed of 7.5 deg s⁻¹. In the baseline/no motion condition only the stimuli used for size estimation were present on the screen (Fig. 1). We omitted an experimental condition with a static display of the stimuli used for background motion in the other tests since earlier work had shown only minor effects of this manipulation on horizontal line bisection [6] and since this was not the focus of the present study. The subject viewed the screen from a distance of 0.5 m with his/her body midline properly aligned to the centre of the screen. Figure 1 sum-

### Table 1. Neglect patients.

<table>
<thead>
<tr>
<th>Patient</th>
<th>Age/gender</th>
<th>Aetiology, lesion</th>
<th>Months since lesion</th>
<th>Field Defect</th>
<th>Clock face (L/R)</th>
<th>Field Sparing (L/R)</th>
<th>Line bisection deviation (mm)</th>
<th>Cancellation omissions (L/R)</th>
<th>Clock face omission (L/R)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>64/f</td>
<td>MCA R temp-par</td>
<td>3</td>
<td>HH, 15</td>
<td>100</td>
<td>yes</td>
<td>+53</td>
<td>1/0</td>
<td>107‡</td>
</tr>
<tr>
<td>2</td>
<td>35/m</td>
<td>MCA R temp-par</td>
<td>2</td>
<td>HH, 11</td>
<td>1/1</td>
<td>yes</td>
<td>+27</td>
<td>1/1</td>
<td>144‡</td>
</tr>
<tr>
<td>3</td>
<td>36/m</td>
<td>MCA R par</td>
<td>4</td>
<td>HH, 10</td>
<td>+56</td>
<td>yes</td>
<td>+61</td>
<td>1/1</td>
<td>183‡</td>
</tr>
<tr>
<td>4</td>
<td>56/f</td>
<td>ICB R basal ganglia</td>
<td>5</td>
<td>HH, 18</td>
<td>+64</td>
<td>yes</td>
<td>+64</td>
<td>1/0</td>
<td>86‡</td>
</tr>
<tr>
<td>5</td>
<td>72/f</td>
<td>MCA R par-temp</td>
<td>6</td>
<td>HH, 15</td>
<td>1/1</td>
<td>yes</td>
<td>+30</td>
<td>1/1</td>
<td>52‡</td>
</tr>
<tr>
<td>6</td>
<td>58/m</td>
<td>MCA R par</td>
<td>7</td>
<td>HH, 20</td>
<td>1/1</td>
<td>yes</td>
<td>+23</td>
<td>1/1</td>
<td>23‡</td>
</tr>
</tbody>
</table>

Clock face: 0 = normal, 1 = omission of numerals on right or left side. Line bisection: deviation from the true midline in mm (+ to the right, – to the left; cut-off \( \pm 5 \) mm. Number cancellation: omission of targets in left/right hemispace. ICB, intracerebral bleeding; HH, homonymous hemianopia; "Patient searched in only the very rightmost part of the test." L, left; R, right, f, female; m, male; temp, temporal; par, parietal.
marizes the experimental setup. The three experimental conditions were presented in a pseudo-random sequence to control series effects. The subjects were instructed to estimate the horizontal size of the left bar, irrespective of the presence or absence of background motion.

Results

Data were analysed using a 2 × 3 (group vs motion condition) analysis of variance for repeated measures for the two dependent variables constant errors and difference thresholds.

Constant errors: All but one patient showed an extreme overestimation of the horizontal size of the rectangle in left hemispace (mean: 20.9 mm or +34.8%) in the no motion condition (baseline). ANOVA disclosed a significant main effect for the factors group (F = 13.45, d.f. = 1, p < 0.004), background motion condition (F = 8.55, d.f. = 2, p < 0.008) and a significant interaction between both variables (F = 11.59, d.f. = 2, p < 0.003). Paired t-tests revealed that the constant errors in the size judgment task were significantly smaller during leftward motion than in the no-motion condition (t = 4.88, p < 0.005, two-tailed) and in the rightward-motion condition (t = −5.4, p < 0.003) in the neglect group. Rightward motion aggravated the deficit present in the baseline condition slightly but not significantly in the neglect group (t = −2.23, p > 0.05, n.s.). No effect of motion condition was seen for the normal subjects (largest t = 0.58, smallest p = 0.59, n.s.).

In four neglect patients a full normalization of the size distortion was achieved during leftward motion (cases 1–4, size deviations < 4 mm or ±7%, see Fig. 2), and in the remaining two even a slight overcompensation was evident (cases 5 and 6, size deviation −15 and −12.5 mm, or −20 and −25%). Figure 2 summarizes the individual results of the neglect patients and normal subjects separately for the three experimental conditions.

Difference thresholds: No significant effects of group (F = 6.36, d.f. = 1, p > 0.05, n.s.) or motion condition (F = 1.811, d.f. = 2, p > 0.05, n.s.) were disclosed, nor was there a significant interaction between both variables in the ANOVA (F = 1.811, d.f. = 2, p < 0.05, n.s.). Table 2 shows the data.

Effects of visual field defects: Inspection of Fig. 2 reveals that the two patients with completely intact visual fields (subjects 3 and 4, marked with an asterisks) show the same modulation of estimated size as the remaining four cases. They differ, however, in the magnitude of this error which is either due to the fact that subject 4 had only a moderate neglect as judged by the screening tests (see Table 1) or their field defect. Nevertheless, since all patients except No. 2 had a field sparing of 15° or more in their left visual field they could see the total screen simultaneously. This makes effects of the associated hemianopia implausible.

Discussion

The present results provide convincing evidence that coherent visual background motion towards the neglected hemispace significantly modulates the perceived horizontal object size, hence the size distortion, in neglect patients when comparing two stimuli.
separated in both hemispaces. This finding indicates that background motion not only affects the subjective straight ahead [10] and subjective midline in line bisection or line extension [4,6,7], but facilitates also the accuracy of spatial judgments concerning two stimuli separated in left and right space.

As we used a drift speed that was too slow to elicit optokinetic nystagmus (OKN) or afternystagmus it seems unlikely that the observed results were caused or affected by OKN. To provoke OKN significantly higher stimulus speeds (50 deg s\(^{-1}\)) are required [11]. Furthermore, the stimulus speed of slow visual background motion had no significant effect on line bisection in a previous study [6]. Hence, the facilitatory effect of leftward motion does probably not result from oculomotor activity (OKN) of the patients. Since we did not include a control condition which evaluated if stationary background stimuli had the same beneficial effect on size judgments it could be argued that the observed improvement of the neglect patients might result from the mere presence of such stimuli and not from their motion. However, the differential effects of left versus right-sided background motion make this assumption implausible. Furthermore, Mattingley and colleagues showed that stationary background stimuli did not improve the ipsilesional line bisection error in neglect patients [6].

How are the present results to be explained? First, it is interesting to note that all six patients of our unselected sample of neglect patients showed a moderate to marked size distortion, ranging up to 50% overestimation of the left-sided bar in some cases. With such a marked size error it is not surprising that rightward background motion did not significantly aggravate this deficit, probably because the neglect patients’ attention was already maximally biased to their ipsilesional, right side. Such an ipsilesional orienting bias has been reported previously in neglect patients [12]. Moreover, the marked deviation of their midline in horizontal line bisection (see Table 1) supports this interpretation (mean deviation to the right: 40.5 mm, or 8.1° when viewed at 40 cm distance). Furthermore, an even larger size error in the rightward motion condition was limited in some cases by the size of the screen.

Another interesting result is that leftward motion reduces the constant errors in the size judgment task, but not the difference thresholds. This indicates that the facilitatory effect is specific for horizontal object size but obviously has no effect on the precision of the sensory discrimination. Finally, it was noted (during the experiment and in the data) that the facilitatory effect of leftward motion was present in all patients from the very first trial. Hence, the latency of the motion effect was rather short, occurring within a few seconds after stimulus presentation.

One possible explanation for our findings is that leftward background motion facilitates the direction of attention towards neglected regions of space [4,6].

Table 2. Mean (s.d.) difference thresholds (mm) in the horizontal size judgment task in six neglect patients and six normal controls.

<table>
<thead>
<tr>
<th></th>
<th>Neglect patients</th>
<th>Normal subjects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline (no background motion)</td>
<td>2.33 (2.21)</td>
<td>1.5 (1.10)</td>
</tr>
<tr>
<td>Leftward background motion</td>
<td>1.92 (1.32)</td>
<td>1.42 (0.92)</td>
</tr>
<tr>
<td>Rightward background motion</td>
<td>0.92 (1.02)</td>
<td>1.50 (1.14)</td>
</tr>
</tbody>
</table>
Another, compatible hypothesis explains the observed motion effect as facilitating the generation of an egocentric space representation by providing a directional, visual input (the background motion) to this disturbed representation. We propose that the largely intact visual motion system, with its many relay stations along striate and extrastriate dorsal visual pathways (including MT, MST, parietal lobe) and even subcortical visual pathways [13] is capable of modulating the neuronal activity in damaged cortical areas, i.e. in the lesioned parieto-temporal cortex of neglect patients. Since severe and persistent deficits in global motion perception are rarely found in patients with unilateral brain lesions (apparently 13%) [14], most of the visual motion system seems to remain functional in neglect patients with right-sided lesions. Our hypothesis is supported by recent imaging studies according to which full-field optokinetic stimulation in healthy subjects [15] of the blind field in hemianopic patients produced significant activations in the occipitotemporal cortex [16,1] and in the basal ganglia [15,16,18] but did not activate the lesioned striate cortex [16,18]. Although the source of these residual activations in the lesioned hemisphere is at present unclear similar residual activations might occur in neglect patients. These could be in part responsible for the facilitatory effect of leftward background motion observed here. These residual activations in the lesioned hemisphere offer therapeutic applications for neglect rehabilitation since motion stimulation obviously exerts a powerful influence on perception, irrespective of the presence of additional hemianopia. As none of our patients reported adverse effects of the slow background motion used here (especially no motion sickness) it would be intriguing to evaluate if repetitive stimulation leads to enduring improvements in patients with neglect, as suggested [17]. Another attractive feature of this technique is that positive effects occur nearly immediately, and that it does not require awareness of the patient but possibly may enhance awareness, at least transiently, as suggested by one of our patients during leftsided motion: “The longer I look at the (left) bar the larger it appears to me.”

Conclusion

Leftward background motion stimulation affects the perceived horizontal size of visually displayed objects in patients with left spatial neglect, thereby alleviating their size distortion in left hemispace. These results suggest that coherent visual motion restores temporarily the disturbed representation of visual object size in extrapersonal space.

References


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