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Modulation of unilateral neglect as a function of direction of object motion

Judith Dunai,[CA,2] Kerry Bennett,[CA] Alissa Fotiades, Ada Kritikos[1] and Umberto Castiello[1]

Faculty of Health Sciences, La Trobe University, Bundoora, Vic 3083; [1]Department of Psychology, The University of Melbourne, Parkville 3052, Australia
[2]Present address: National Ageing Research Institute, Poplar Rd, Parkville, Vic 3052, Australia

[CA]Corresponding Authors

UNILATERAL neglect is a disorder involving difficulty in attending to the side of space contralesional to brain injury. Two recent experiments have shown that task-irrelevant background motion reduces neglect on line bisection tasks; however, task-relevant motion has not been assessed. We investigated the effect of task-relevant object motion on left neglect using a moving cube presented on a computer screen. Subjects responded to cued corners of the cube as it moved across the screen. Direction of cube motion had a significant impact on the magnitude of neglect. Responses to left hemispace targets appearing on a leftward moving cube were equal to patients' fastest responses. In contrast, responses to left hemispace targets appearing on a rightward moving cube were the slowest of all responses. These results demonstrate that contralesional object motion is capable of normalising neglect patients' detection of contralesional targets. *NeuroReport* 10:1041–1047 © 1999 Lippincott Williams & Wilkins.

Key words: Attention; Direction of movement; Object motion; Visuospatial neglect

Introduction

Unilateral neglect is an attentional disorder which is often seen following unilateral brain damage and consists of a failure to orient or respond to the contralesional side of space. It is not the result of visual sensory loss as it occurs in patients with no demonstrable visual field defects [1]. Furthermore, the neglected side of space appears to be computed in egocentric rather than retinotopic co-ordinates [2], and there are patients in whom decreased awareness of contralateral objects is only evident when simultaneously presented ipsilateral objects also compete for attention [3]. These findings make it clear that neglect is a disorder of attention rather than vision. Unilateral neglect is more common following right hemisphere brain damage, when it results in left neglect, and can consist of neglect of contralesional space [1,4–5], the contralesional side of objects [6-7], or both [8]. Directional attention-shifting deficits are also observed: neglect patients have great difficulty shifting attention towards contralesional space, and are abnormally attracted to ipsilesional space [4,5,9,10].

A number of experimental manipulations reduce manifestations of neglect. These generally involve spatial cues likely to increase the allocation of attentional resources to contralesional space [1,11,12]. For example, Làdavas *et al.* [11] trained neglect patients to orient attention contralesionally using a central arrow presented on a computer screen, and observed a dramatic reduction in the number of errors to contralesional targets following a 6-week training period. Weinberg *et al.* [12] found that repeated visual scanning practice improved neglect patients' reading and writing performance. Two recent experiments [13,14] demonstrated that leftward background motion during performance of line bisection tasks can reduce left neglect, or even produce right neglect. These studies all show that experimental manipulations likely to increase leftward orienting of attention can reduce neglect of contralesional space.

Several experiments have shown that motion is a particularly salient spatial cue in non-brain-damaged individuals [15–18]. Performance on detection tasks is facilitated when target location is correctly indicated by object motion [15]. Attention cued to an object prior to its movement travels with it, resulting in faster subsequent processing of its features [16]. Items distinguished by the direction of their movement capture attention even when task irrelevant [17]. Finally, moving objects are attentively tracked even when moving away from the most likely location of the imperative target [18]. Although there has been little research into the cueing effects of object motion in unilateral neglect, the results of background motion studies [13,14] suggest that similar cueing effects of object motion would occur in patients with neglect. This is particularly likely given evidence of normal motion detection thresholds, and normal perception of motion direction in neglect patients [19] and patients with visual extinction [20] (a disorder with a similar functional and neurophysiological profile). Given the powerful attraction of object motion in non-brain-damaged individuals and background motion in patients with neglect, and evidence of normal motion perception in unilateral neglect, we predicted that the presence of an object moving towards contralesional space would reduce manifestations of neglect by directing attention towards the neglected side of space. We tested this hypothesis in neglect and non-brain-damaged control subjects using cued targets appearing on leftward and rightward moving 3D cubes presented on a computer screen.

Materials and Methods

Subjects: Two patients with unilateral neglect and four non-brain-damaged controls participated in the experiment. The two patients were a 51-year-old female (P1) and a 67-year-old male (P2), both of whom were diagnosed with left neglect in the period immediately following right middle cerebral artery cerebrovascular accidents (CVAs) resulting in predominantly right parietal damage (confirmed by CT scans interpreted by senior radiologists). Table 1 provides a summary of radiologists' findings. Both patients participated in the experiment between 1 and 3 months post-CVA. At the time of assessment P1 showed mild signs of neglect on standard clinical tests (e.g. line, shape and letter cancellation, line bisection, copying and drawing). This took the form of a tendency to miscopy and misdraw details on the left side of drawings. She also showed signs of left-sided extinction on a computerized extinction test. P2's neglect had resolved on standard clinical tests at the time of experimental assessment. Neither patient had any visual field defects (determined by confrontation tests administered by neurologists). Both were right handed. The control subjects consisted of two females aged 49 and 51 years, and two males aged 36 and 67 years. All were right handed and had normal or corrected to normal vision. The experiment was approved by the La Trobe University and St. Vincent's Hospital Human Research Ethics Committees, and all subjects gave written informed consent.

Materials: Stimuli were presented on a 24×32.5 cm Silicon Graphics computer screen. The object used in the experiment was a cyan-colored 3D 2 cm^3 cube appearing against a black background and generated using a Silicon Graphics O_2 workstation. The angle of cube presentation was such that the front face of the cube was directed $\sim 25°$ to the left edge and 10° to the lower edge. The angle subtended by the cube was 2° 17′. Trials began with the presentation of a white fixation cross (6×6 mm, visual angle 4′ 11″) in the centre of the screen. This was followed by the appearance of the cube 8.75 cm from the left or right edge of the screen and 16 cm from the bottom of the screen (visual angle 8° 11′). After a variable interval the cue appeared (highlighting of one right-angle of the cube with heavy white lines), followed by the target (highlighting of the right-angle in heavy red lines). The cue and target could appear on any corner of either the left or right side of the cube. All trials were valid (the cue accurately indicated the location of the target on the object). Ten percent of trials were catch trials (i.e. trials in which no target was presented).

Stationary cube trials: The cube could appear on the left or right side of the screen (in left or right

Table 1. Summary of CT scan findings for neglect patients (information obtained from radiologists' reports)

Patient	Diagnosis	Specific findings
P1	Large right MCA infarct affecting parietal cortex and temporal lobe	Large low density lesion in right parietal cortex and right temporal lobe Effacement of overlying sulci and underlying right lateral ventricle No other focal damage identified No left cerebral hemisphere abnormality detected
P2	Right MCA infarct affecting parietal region	Area of low attenuation involving grey and white matter in right parietal region No other focal damage identified No left cerebral hemisphere abnormality detected Normal ventricular size and configuration

hemispace) (see Fig. 1a–c,d–f). Trials were grouped into four blocks according to hemispace of cube appearance and side of cube on which cue and target were presented. Cube-cue and stimulus onset asynchrony (SOA) intervals were 50, 200 and 300 ms and 150, 250 and 350 ms, respectively. Cue durations were 150, 300 and 600 ms. Cube-cue and SOA intervals, and cue durations were randomized across trials to decrease expectancy effects. The stimulus duration was 100 ms.

Moving cube trials: The cube could appear on the left or right side of the screen. It then moved smoothly across the screen at a speed of 3 cm/s. Trials were presented in four blocks according to direction of cube motion and side of cube on which cue and target appeared. Within each block of trials, the cue and target could both appear on the left side of the screen (left hemispace trials), on the right side of the screen (right hemispace trials) or the cue could appear on one side of the screen and the target on the other (centre trials; see Fig. 2a–c,d–f). Cube-cue intervals varied depending on direction of cube movement and side of screen (hemispace) of cue and target presentation. When cue and target both appeared on the side of the screen from which cube movement commenced, cube-cue intervals ranged from 0 to 1710 ms. When the cue and target both appeared near the centre of the screen, cube-cue intervals ranged from 1480 to 2180 ms. When the cue and target both appeared on the opposite side of the screen from which cube movement commenced cube-cue intervals ranged from 2870 to 3790 ms. SOA intervals were 833, 1000 and 1167 ms, respectively. Cue durations were 150, 300 and 600 ms. Cube-cue and SOA intervals, and cue durations were randomized across trials. The stimulus duration was 100 ms.

Control subjects' eye movements were monitored using infrared eye tracking equipment (Applied Science Laboratories, Model 210) mounted on an adjustable head and chin rest. Trials containing eye movements > 1° of visual angle were automatically discarded. It was not possible to use eye tracking equipment with neglect patients, whose eye movements were therefore monitored using a mirror.

Procedure: Subjects were seated comfortably in front of the computer screen with the head positioned in an adjustable head and chin rest so that the distance between the eyes and the screen was held constant at ~50 cm. They were instructed to focus on the central cross and to respond by pressing a button as soon as they became aware of the target. They were told that it was important not to move their eyes away from the cross and that trials in which they did this would be automatically discarded and repeated. Subjects completed two sessions (a stationary cube and a moving cube session) each consisting of four blocks of 45 (non-rejected)

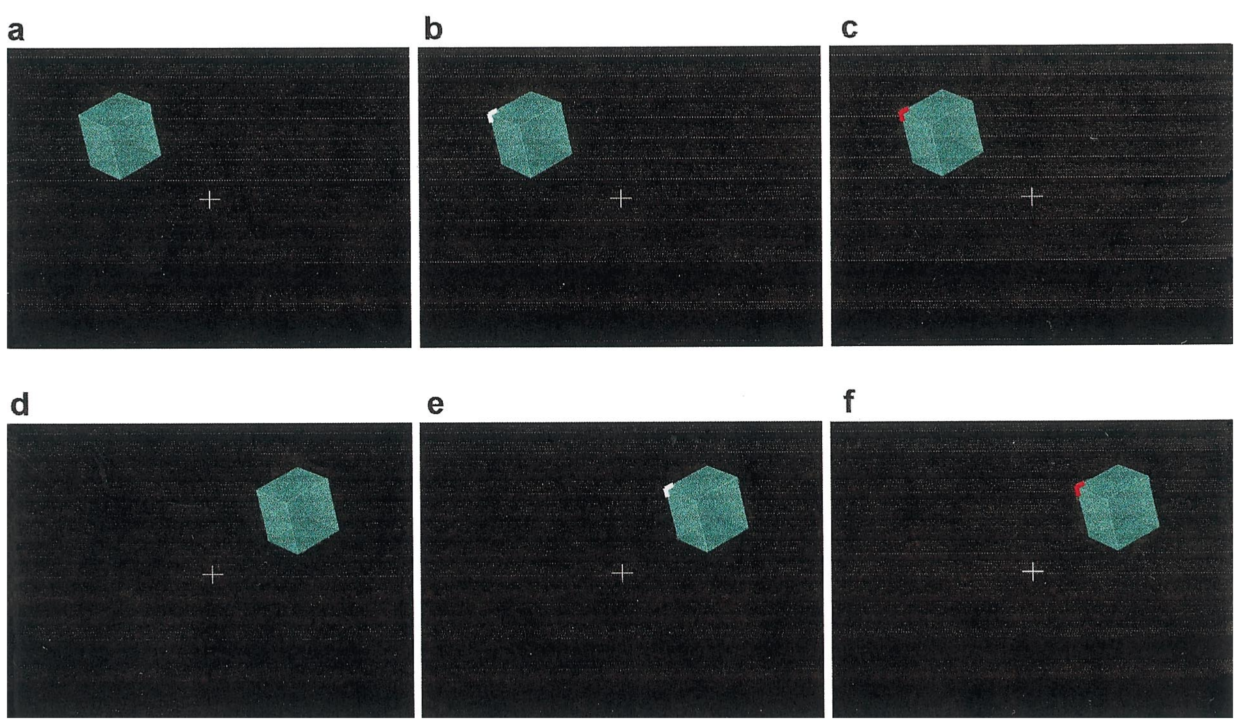

FIG. 1. Presentation of the perceived 3D cube on stationary cube trials. (**a–c**) Left hemispace trials, (**d–f**) right hemispace trials. Trials began with the appearance of a central fixation cross, followed by the appearance of the cube (a,d), the cue (white highlighting of a corner of the cube; b,e) and the target (subsequent red highlighting of the same corner; c,f). The cue and target could appear on any corner of the left or right side of the cube.

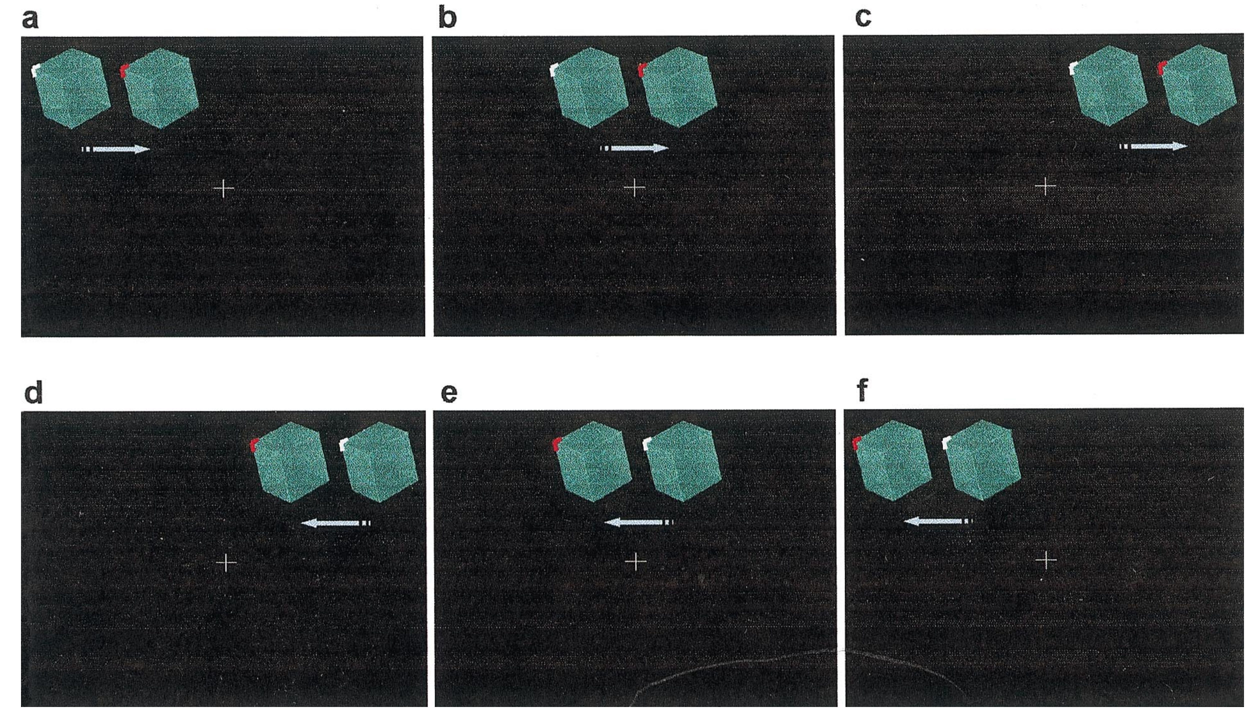

FIG. 2. Presentation of the cube on moving cube trials. (**a**–**c**) Left, centre and right hemispace cue and target positions when the cube moved from left to right. (**d**–**f**) Right, centre and left hemispace cue and target positions when the cube moved from right to left. As in stationary cube trials, the cue and target could appear on any corner of the left or right side of the cube

trials. The order of sessions, and of blocks within sessions was counterbalanced across subjects.

Data analysis: Data for each of the neglect subjects were analysed individually using independent factorial ANOVAs. Data for control subjects were averaged across conditions to obtain group means which were entered into repeated measures factorial ANOVAs. For both neglect and control subjects, stationary cube data were analysed using 2×2 (hemispace × side of object) ANOVAs, and moving cube data using $2 \times 3 \times 2$ (direction of motion × hemispace × side of object) ANOVAs. Comparisons between stationary and moving cube responses were analysed using 3×2 (motion condition × hemispace) ANOVAs. Differences between individual means were assessed using Newman-Keuls *post hoc* procedures.

Results

Stationary cube results confirmed the presence of either left hemispace or left object neglect in both patients. P1's responses to left hemispace targets were significantly slower than responses to right hemispace targets ($F(1,153) = 12.88$, $p < 0.001$). A significant hemispace × side of object interaction indicated that left hemispace responses were slowest when targets appeared on the left side of the cube ($F(1,153) = 7.45$, $p < 0.01$). P2's responses to targets appearing on the left side of the cube were significantly slower than responses to targets appearing on the right side of the cube ($F(1,149) = 13.451$, $p < 0.001$), and there was a non-significant trend for left hemispace responses to be slower than right hemispace responses. There was no evidence of left–right asymmetry in control subjects' data.

Moving cube data revealed a highly significant direction × hemispace interaction in both neglect and control subjects, indicating that responses were fastest to targets appearing towards the end of cube motion. When the cube moved towards the right, responses to right hemispace targets were faster, and when it moved towards the left, responses to left hemispace targets were faster (Fig. 3). The same basic pattern of results was observed in both groups of subjects, except for the presence of significant left neglect in the two patients. However, left hemispace neglect was observed only when the cube moved towards the right. When the cube moved towards the left, patients responses to left hemispace targets were equal to their fastest responses (Fig. 3). Comparison of moving and stationary cube data indicated that neglect patients' responses to left hemispace targets appearing on a leftward moving cube were significantly faster than their stationary cube responses ($p < 0.01$), while responses to left hemispace targets appearing on a rightward moving cube were significantly slower than stationary cube responses ($p < 0.01$; Fig. 4).

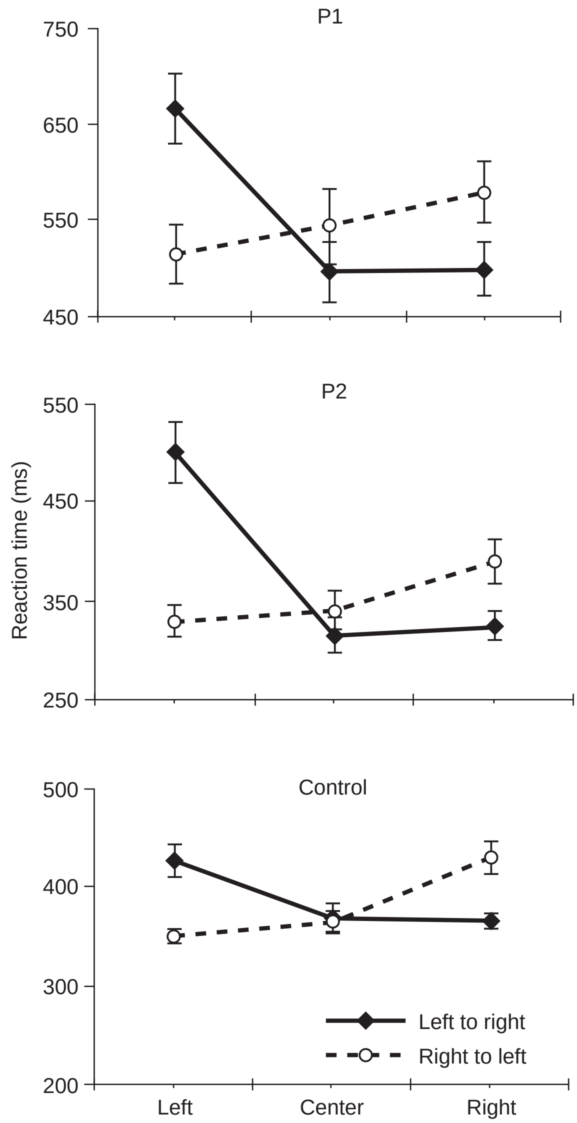

FIG. 3. Responses to left, centre and right hemispace targets as a function of direction of cube motion. Significant direction by hemispace interactions were observed in P1 ($F(2,153) = 9.4$, $p < 0.0005$), P2 ($F(2,137) = 16.87$, $p < 0.0005$) and control subjects ($F(2,6) = 33.05$, $p = 0.001$). Despite the presence of significant left-right asymmetry in the neglect patients (left to right, left hemispace *vs* right to left, right hemispace) there was no significant difference between left to right, right hemispace responses and right to left, left hemispace responses, indicating the absence of neglect when the cube moved towards the left.

Discussion

The results of the present experiment revealed a highly significant interaction between direction of cube movement and hemispace of target presentation in both neglect and control subjects. This interaction reflected subjects' faster responses to targets appearing towards the end of cube movement. Responses to left hemispace targets were fastest when the cube moved from right to left, while responses to right hemispace targets were fastest when the cube moved from left to right. This response pattern suggests that direction of cube motion acted as a spatial cue. Leftward cube motion cued attention to the left, while rightward cube motion cued attention to the right. The cueing effect of cube motion followed the same basic pattern in all subjects; the only difference between neglect and control subjects was the presence of significant left neglect which was evident in patients only when the cube moved towards the right.

The most remarkable aspect of the results was the apparent absence of neglect when the cube moved towards the left. Neglect patients' responses to left hemispace targets appearing on a leftward moving cube were equal to their fastest responses. This is in marked contrast to the significant neglect observed when the cube moved towards the right: responses to left hemispace targets appearing on a rightward moving cube were the slowest of all responses in both patients. In other words, when the direction of cube motion cued attention to the left there was a reduction in neglect, but when cube motion cued attention to the right, significant left neglect was evident.

This interpretation is supported by comparison of stationary and moving cube data. Patients' responses to left hemispace targets appearing on a leftward moving cube were significantly faster than their responses to left hemispace targets appearing on a stationary cube. In contrast, responses to left hemispace targets appearing on a rightward moving cube were significantly slower than stationary cube responses. This suggests that the left neglect evident during stationary cube trials was reduced when cube motion directed attention to the left (i.e. towards the neglected side of space), and exaggerated when it directed attention to the right (away from the neglected side of space).

The above results demonstrate that object motion is a powerful spatial cue which is capable of directing attention towards the neglected side of space in patients with unilateral neglect. They are also consistent with the results of previous experiments showing that manipulations designed to direct attention towards contralesional space can reduce manifestations of neglect [4,5,11,12], and with experiments showing that leftward background motion can reduce left neglect, or even produce right neglect [13,14]. The increased neglect observed when cube motion directed attention towards the right is also consistent with these experiments. This is because a cue directing attention away from the neglected side of space would be expected to exacerbate neglect patients' tendency to miss contralesional targets, particularly given the rightward orienting bias frequently observed in unilateral neglect [4,5,9,10].

The effectiveness of motion as a spatial cue in unilateral neglect is consistent with observations of

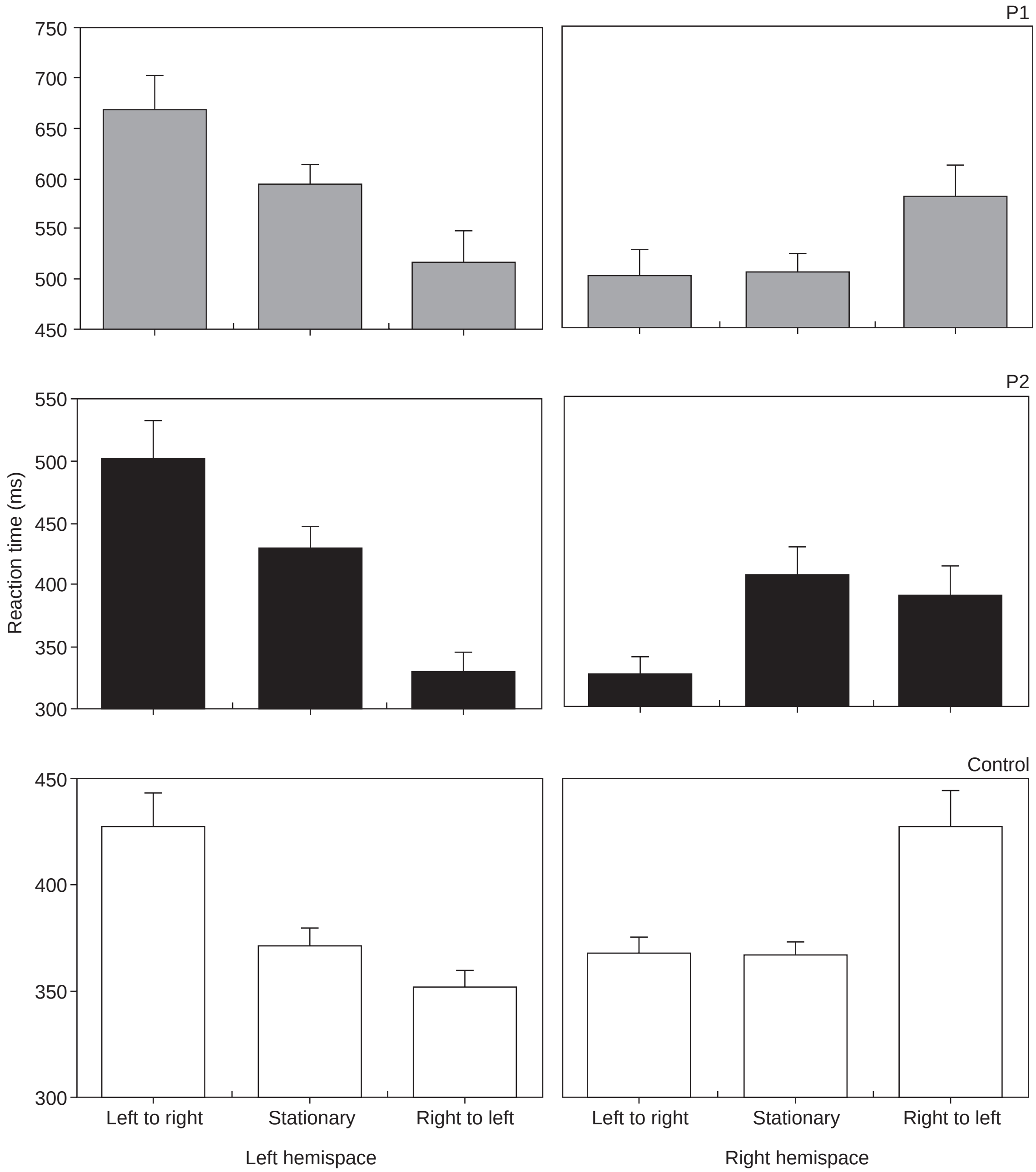

FIG. 4. Responses to left and right hemispace targets as a function of motion condition (left to right, stationary and right to left). For left hemispace trials, neglect patients' responses to leftward moving targets were significantly faster than responses to stationary targets, which were significantly faster than responses to rightward moving targets ($p < 0.01$ in all cases). This pattern, suggestive of decreased neglect when the cube moved towards the left, and increased neglect when the cube moved towards the right, was not observed for right hemispace trials (right side of graph).

intact motion perception in individuals with neglect or visual extinction [19,20]. It is also consistent with human PET and fMRI studies in which areas MT/V5, V3A and pMSTd have been identified as the locus of both real and illusory motion perception in non-brain-damaged individuals [21–23], and with neuropsychological studies indicating that disorders of motion perception are associated with occipito-temporal rather than parietal lesions [24,25]. Considered together, these data suggest that parietal lesions producing unilateral neglect would be unlikely to affect motion perception. Thus motion-derived spatial cues appear to be one source of stimulus-driven spatial information which is still available to patients with unilateral neglect.

The finding that responses to left hemispace targets presented on a leftward moving cube were equal to patients' fastest responses suggests that the use of task-relevant moving cues has considerable rehabilitative potential. The importance of motion is suggested by the lower response times for stimuli presented on moving as opposed to stationary cubes.

Further, although task-relevant stationary cues (e.g. brightening of peripheral boxes or central arrows [4,5]) have been shown to reduce neglect, the effects were not as dramatic as that observed in the present experiment. Thus it appears that moving cues are better than stationary cues, presumably because attention is first attracted on neglect patients' 'good' right side, and then guided towards the 'bad' left side. Given that performance is not necessarily enhanced with continuous leftward cueing of background motion (e.g. patients frequently bisect lines far to the left of centre) [14], we also propose that task-relevant object motion facilitates contralesional stimulus detection more effectively than task-irrelevant motion. This is probably because task-relevant motion directs attention to the exact location of potential targets rather than merely inducing a more generalized leftward orienting of attention.

In conclusion, our results demonstrate that direction of object motion is a powerful attentional cue. In both control and neglect subjects, responses to left hemispace targets were fastest when cube motion directed attention to the left, while responses to right hemispace targets were fastest when cube motion directed attention to the right. Although neglect patients showed signs of left hemispace neglect superimposed upon the cueing effect of object motion, this was evident only when cube motion directed attention to the right (i.e. away from the neglected side of space). When cube motion directed attention towards the left, responses to left hemispace targets were equal to patients' fastest responses. This suggests that direction of object motion is a powerful spatial cue which is capable of dramatically reducing manifestations of neglect when it directs attention towards contralesional space.

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