

## PERIPERSONAL AND VERTICAL NEGLECT

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### SUMMARY

When bisecting radial lines visually, normal subjects err towards distant peripersonal space, and when bisecting vertical lines visually, they err towards upper vertical space. In contrast, when bisecting lines under tactile-proprioceptive guidance, subjects err towards near peripersonal space, suggesting that normally attention is preferentially distributed away from the body during visual exploration but distributed towards the body during tactile exploration. A patient with ischaemic lesions, however, involving both inferior temporal lobes neglected far peripersonal and upper vertical space. He also demonstrated a motor bias away from the neglected space. These findings suggest that in man attention is spatially directed in three orthogonal axes (horizontal, vertical and radial), that attention may normally be unequally distributed in each of these axes, and that neglect may occur in not only the horizontal axis but also in the radial and vertical axes.

### INTRODUCTION

An individual with neglect fails to respond to novel or meaningful stimuli despite the preservation of elementary sensory and motor function (Heilman *et al.*, 1985b). Neglect has been attributed to deficits both in attentional and intentional (motor preparatory) processes. The behavioural manifestations of neglect are usually most profound in extrapersonal and body space contralateral to hemisphere lesions, most often left hemisphere as defined by the midsagittal plane. Head and body midline are important determinants of the neglected spatial field, and the visual half-field has relatively less influence (Bowers *et al.*, 1981; Heilman *et al.*, 1987).

Several observations, however, suggest that neglect may occur in other fields of extrapersonal space and therefore that attentional-intentional processes may be organized in a more complex manner. First, many subjects with left hemispatial neglect fail to cancel most targets in the left lower quadrant (Morris *et al.*, 1985). Secondly, extinction and neglect of stimuli in the lower visual fields have recently been reported in man (Rapcsak *et al.*, 1988). Finally, neglect of percutaneous stimuli has been reported in monkeys (Rizzolatti *et al.*, 1983). We recently evaluated a man for multimodal neglect of upper space and distant extrapersonal space and compared him with 12 control subjects.

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## METHODS

*Subject*

A 66-yr-old right-handed white man with an eighth grade education who worked as a house painter was transferred to the Veterans Administration Medical Center in Gainesville, Florida, from an outside hospital following a stroke. He experienced the sudden onset of headache, visual loss, and right-sided weakness in the evening, and the following morning he was found to be blind with mild left-sided paresis and decreased arousal. His deficits improved over several days, and he was left with inconsistent visual field loss and a severe anterograde amnesia. The aetiology of his stroke was presumed to be embolic from a cardiac source; mitral annulus calcification but no thrombus was demonstrated on echocardiography. He had a pacemaker inserted for atrial fibrillation and sinus pauses of 2–3 s and he was maintained on digoxin, quinidine, verapamil and warfarin.

Six weeks after his stroke he was alert and cooperative but distractable, with motor imperisistance for eye closure and arm extension. He was generally hypokinetic, and there was a paucity of spontaneous speech. Language was fluent with good repetition and naming. Comprehension of conversational speech was normal but he had some difficulty with complex sequential commands. He was disorientated for time and place, had a severe anterograde amnesia for verbal and figural material, and a relatively extensive retrograde memory deficit extending 20 yrs into the past. Verbal fluency was 1 item in 60 s; praxis, simple calculations, right/left orientation, and finger recognition were normal. Insight, general knowledge, vocabulary, abstract reasoning and problem solving were compatible with his educational and occupational level. He had a stable bilateral upper hemivisual field loss, which was complete except for the ability to detect and localize light. Pursuit eye movements in all directions were broken into small saccades. Visual function improved to the point where he was able to discriminate high contrast gratings with a period of less than 30 min arc, and he localized target dots of less than 12 min arc diameter. Optokinetic nystagmus was elicited with 25 min arc gratings to right, left and upward stimuli, resulting in downward saccades. He traced drawings of standard line widths with his right index finger but was unable to identify figures on the usual charts for estimating visual acuity. He accurately localized all light stimuli under visual guidance for targets in the lower visual fields by reaching out with his right hand, but made a systematic error towards the lower right when reaching for targets in the upper visual fields. His error was 3–4 cm for targets in the right upper quadrant and 30–40 cm for targets in the left upper quadrant. He was aware of his errors and perplexed by them. To isolate the effect of spatial field on reaching behaviour, target location in the visual field was controlled by having the patient fixate the target. When fixating targets placed in various spatial fields, he accurately localized them in lower hemispace (below eye level) but made systematic errors in reaching for targets in upper hemispace (fig. 1). He was unable to differentiate relative line

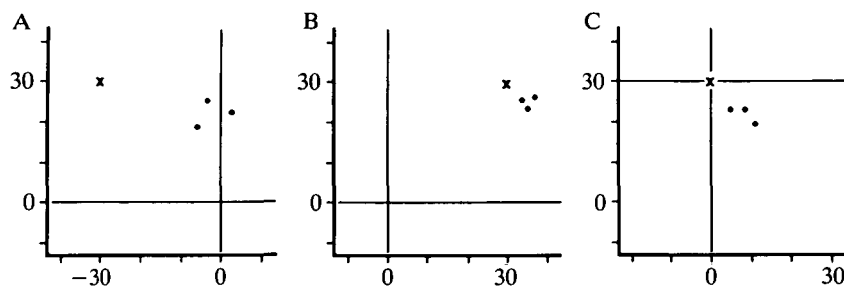


FIG. 1. Visual mislocalization by reaching for a point of light (A) viewed in left upper visual quadrant, 30 cm above eye level; B, viewed in right upper visual quadrant; and C, fixated 30 cm above eye level. x = target; dots = response; zero vertical displacement is eye level, zero horizontal displacement is body midline. The intersection of coordinate lines indicates the point of visual fixation in each case.

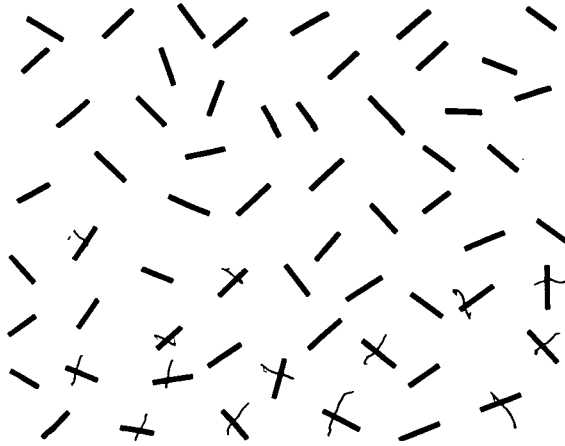


FIG. 2. Line cancellation task presented free-field on desk top (transverse plane), 30 cm from body surface.

orientations of less than  $90^\circ$  but could differentiate circle size differences of 2 mm. A complete description of his apperceptive visual agnosia, colour agnosia, and prosopagnosia will be reported elsewhere.

This man demonstrated left hemispatial neglect on line bisection and cancellation tasks (fig. 2). In addition, he failed to cancel targets in the upper quadrants and misbisected vertical lines below midpoint. He neglected upper and left portions of drawings, in copying figures and in tracing, but completed them when the stimulus figures were inverted. Numbers clustered in the right lower quadrant of his drawing of a clock (fig. 3).

He had mild bilateral paratonic rigidity ('Gegenhalten'), worse on the right, and mild weakness of the right deltoid and triceps and left upper extremity generally. The tendon reflexes were brisk in the left upper and lower extremities and the plantar responses were extensor bilaterally. There was mild dysmetria and intention tremor in the left arm, and he had mildly decreased proprioception in the fingers of the right hand. There was, however, no dysmetria in the right arm as evidenced by normal finger-nose testing with eyes closed. Crude sensation, tactile object and number recognition, and tactile and proprioceptive point localization on the body and in space were normal as he was able to locate the opposite hand in space

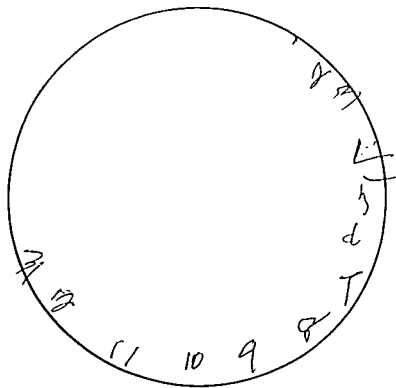


FIG. 3. Drawing of clock.

with eyes closed. CT scans documented the evolution of bilateral inferior temporal lobe and deep occipital lobe ischaemic infarction, worse on the left, but no evidence of parietal lobe pathology (fig. 4).

He was seen in follow-up 6 months after his first evaluation. At this time his visual acuity was testable with a Snellen eye chart because of improvement in number recognition, and his acuity had improved to 20/100 in the right eye and 20/200 in the left. His visual field had enlarged to approximately 60° above the horizontal meridian at their maximum using moving or stationary solid targets, but varied in size from day to day. On some days he had only 20° of vision in the superior visual quadrants, and he demonstrated significant fatigue over the course of each testing session such that a region of visual inattention for stationary stimuli gradually replaced the visual extinction in upper visual fields, and finally no visual function could be documented above the horizontal meridian at the end of the test session on some days. Upper visual quadrant extinction was clearly demonstrated for stimuli (90° movement of the examiner's index finger) presented simultaneously in upper and lower visual quadrants in each of the right and left hemifields. Right-sided tactile extinction was present, and right visual extinction was demonstrable only for stimuli presented

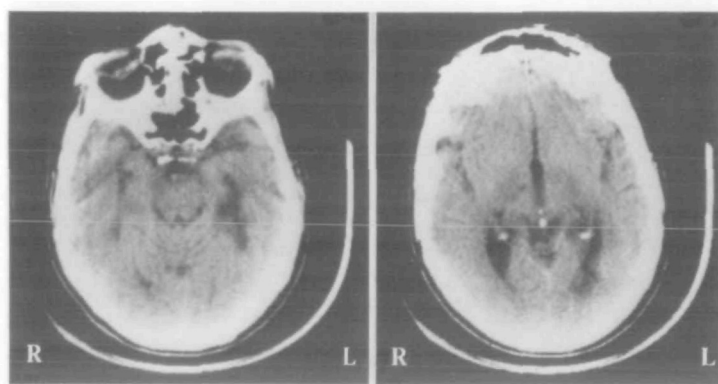


FIG. 4. CT scan at the level of A, inferior temporal lobes, and B, calcarine cortex 6 weeks poststroke, revealing hypodense lesions in posterior medial temporal lobes (fusiform and lingular gyri), left greater than right, and dilated occipital horn of the left lateral ventricle.

simultaneously in both superior quadrants. There was no extinction of peripheral targets when central and peripheral stimuli were presented simultaneously in the lower visual fields. Testing for extinction of distal versus proximal stimuli in peripersonal space was more difficult and limited by the degree of preserved superior quadrant vision. Nonetheless, on some occasions an upper visual field stimulus was no longer extinguished when presented 30 cm closer to the subject's face than a simultaneous stimulus in the lower visual quadrant. Visual mislocalization toward the lower right was still present but of lesser degree.

### Controls

There were 12 control subjects, 8 male and 4 female. Eight were selected from the orthopaedic and internal medicine inpatient service (controls 1–8) after excluding active central nervous system disease, a past history of stroke, seizures, dementia, malignancy, major psychiatric disorder, or evidence of decreased arousal or neglect on screening neurological examination. The mean age of the hospital controls was 57 yrs and their mean educational level was 10 yrs. Four healthy volunteers also participated (controls 9–12) and had a mean age of 35 yrs.

To evaluate the nature of this patient's neglect more fully, his performance was tested using a line bisection task under a variety of spatial conditions, and we compared his performance with that of control subjects.

### Apparatus and procedures

Subjects were asked to bisect single black lines of 2.5 mm width and of six different lengths (20, 22, 24, 26, 28, 30 cm), and centred on a 21.6×35.5 cm page (visuomotor condition). Stimuli were presented in blocks of 12 trials, 2 of each length, in a pseudorandomized fashion. Stimuli were located in 12 different areas of egocentric extrapersonal space for the patient, along 3 orthogonal axes (fig. 5). Horizontal lines were presented in the usual fashion with pages in the transverse plane flat on a tabletop and with lines orientated along the intersecting frontal (coronal) plane 30 cm in front of the subjects (horizontal condition).

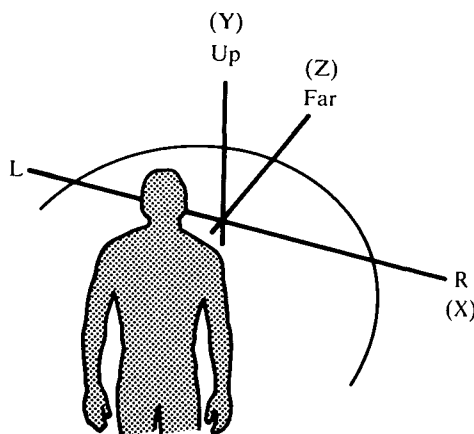


FIG. 5. The region of egocentric extrapersonal space studied; stimuli aligned along three orthogonal axes.

Vertical lines were presented on pages 30 cm in front of the subjects at the intersection of the frontal and midsagittal plane (vertical condition). Radial lines were presented on pages in the transverse plane at table level with lines orientated along the intersection of the midsagittal plane (radial condition). Stimuli were placed in 3 locations along the horizontal axis: with midpoint approximately 30 cm right, 30 cm left, or at the midline. Stimuli were also placed in 3 locations along the radial axis: with pages adjacent to the body surface (near), with the line midpoint approximately 30 cm (middle), or 60 cm (far condition) from the subject; and in 6 locations along the vertical axis, from 15 cm above eye level to 60 cm below eye level. Three blocks of 12 trials were presented in each radial location, and one block of 12 trials were presented in the horizontal and vertical locations. The order of presentation of blocks of trials was counterbalanced to control for the effects of practice and fatigue, and test sessions were limited to 1 h. It was required that the subject explore the full extent of the test line before attempting to bisect it, there was no time limit for completion of the task, and he/she was reminded of the instructions when necessary.

A tactual-motor line bisection task was given to the subjects by using wooden rods of 2.5 mm width and again of 6 lengths (20, 22, 24, 26, 28, 30 cm). One block of 12 trials was presented in each of the following locations: far-radial, eye level vertical, and right and left-horizontal. The subject's index finger was placed on the end of the rod, and he was instructed to explore the rod and find the midpoint while blindfolded. Again, the subject was required to explore the full extent of the stimulus and to identify both ends of the rod before attempting to bisect it. They were started at one end of the rod in half of the trials and at the opposite end in the other half, the order of the starting point being varied pseudorandomly.

The test procedures for the controls were the same as for the patient except that only one block (12 trials) was presented in each of 6 locations for the visuomotor task: near and far space along the radial

dimension, right and left hemispace, and at eye level and 30 cm below eye level in the vertical dimension. Rods were presented in 4 locations for the tactuomotor task: near, far, eye level, and 30 cm below eye level. In addition to the noncued line bisections in the visuomotor condition, both the patient and the control subjects were presented with an equal number of cued line bisections where subjects were required to name letters at the line ends before performing the bisection to document that the subject had attended to the entire line.

### Analysis

Visual line bisection error was measured to an accuracy of  $\pm 1$  mm from the true midpoint, and the mean error and SD in cm were calculated for each condition. Tactile bisections were measured to an accuracy of 0.25 cm. The direction of the error along each dimension was arbitrarily assigned a (+) or (−) value. Errors to the right of midpoint of horizontal lines, above the midpoint of vertical lines, and beyond the midpoint of radial lines, were assigned (+) values whereas errors to the left, below, or near the midpoint for radial lines were given (−) values. To facilitate interpretation of the results, the definition of egocentric extracorporeal space was elaborated to specify regions of space with particular relevance in terms of behaviour. Extracorporeal space was divided into peripersonal space, within arm's reach, and extrapersonal space, beyond arm's reach. Peripersonal space was further divided into near space, immediately adjacent to the body surface, middle and far peripersonal space. Location may be specified in a polar coordinate system, along a radius extending from body centre and orientated at a given angle from the anterior midsagittal line in a plane transverse to the long axis of the body. Such a system does not diminish the importance of bilateral symmetry in the concept of extracorporeal space but radial distance from the individual may influence performance independently within a given hemispace.

The mean line bisection error (LBE) in cm was calculated for each block of trials for both patient and controls across the 5 bisection tasks (visual-vertical, visual-radial, visual-horizontal, tactile-vertical, tactile-radial). The control data from these 5 tasks were analysed using repeated measures analysis of variance (ANOVA). For all analyses, the mean LBE was compared with zero (i.e., the actual midpoint) by constructing a null set of data.

Separate ANOVAs were performed for the 3 visual bisection tasks, using Position (eye level vs below eye level for the vertical task; near vs far for the radial task; left vs right for the horizontal task); and Cue (cued, uncued), and Data (actual, null) as within-subject factors. Separate ANOVAs were also performed for the two tactile tasks using Position (eye level vs below eye level for the vertical task; near vs far for the radial task) and Data (actual, null) as the within-subjects factors.

The mean age of the control group was 1 SD less than the age of the patient (66 yrs); the control group was therefore divided into subjects older ( $n = 5$ ) and younger ( $n = 7$ ) than 55 yrs. The mean age of the older group was 65.4 yrs ( $SD = 8.73$ ), and the two groups were compared by ANOVA. As there was no significant difference in LBE between the young and older control subjects on any of the 5 tasks just described, the data for the whole control group were pooled for subsequent comparisons with the patient.

## RESULTS

As shown in Table 1, for the 3 visual line bisection tasks, results of the ANOVAs indicated that controls significantly misbisected radial [ $F(1,11) = 19.63$ ,  $P = 0.001$ ] and vertically placed lines [ $F(1,11) = 36.38$ ,  $P = 0.0001$ ], whereas horizontal lines were not significantly misbisected [ $F(1,11) = 2.96$ ,  $P = 0.11$ ]. All remaining effects and interactions were nonsignificant, that is, cueing did not affect bisection performance across any of the spatial conditions [radial:  $F(1,11) = 2.11$ ,  $P = 0.17$ ; vertical:  $F(1,11) = 1.26$ ,  $P = 0.28$ ; horizontal:  $F(1,11) = 0.02$ ,  $P = 0.90$ ]. The data from the two conditions were pooled for each location in subsequent analyses. There was a trend for vertically presented lines to be more accurately bisected when positioned below eye



TABLE 1. LINE BISECTION ERROR: MEAN OF 12 CONTROL SUBJECTS

	Mean (cm)	SD	<i>t</i> *	<i>P</i> value
Visual				
Near	0.65	0.66	3.26	<0.01
Far	0.90	0.66	4.54	<0.001
Eye level	0.75	0.42	5.95	<0.0001
Below	0.54	0.40	4.52	<0.001
Tactile				
Near	-0.09	0.68	-0.40	n.s.
Far	-0.92	0.99	-2.78	<0.05
Eye level	-0.34	1.42	-0.72	n.s.
Below	-0.38	1.11	-1.03	n.s.

\* One sample, two-tailed *t* test, *df* = 11. (+) values for LBE beyond midpoint (radial) or above midpoint (vertical); (-) values for LBE near midpoint or below midpoint.

level ( $X = 0.54$  cm,  $SD = 0.40$ ) than when positioned at eye level ( $X = 0.75$ ,  $SD = 0.42$ ), indicating a gradient of response similar to that seen in hemispatial neglect [ $F(1,11) = 4.60$ ,  $P = 0.055$ ].

The control group's means for the 2 tactile bisection tasks (vertical, radial) are presented in Table 1. Results of the ANOVAs indicated that control subjects significantly misbisected radially positioned lines [ $F(1,9) = 11.12$ ,  $P = 0.0087$ ]. In addition, there was a trend for radial lines in near peripersonal space to be more accurately bisected than lines in far peripersonal space [ $F(1,9) = 3.47$ ,  $P = 0.095$ ], indicating another gradient of response like that observed in hemispatial neglect. No significant main effects or interactions were observed in the vertical tactual line bisection task [ $F(1,9) = 1.02$ ,  $P = 0.034$ ].

Finally, the visual and tactile bisection tasks were directly compared for each spatial condition (radial, vertical) in separate ANOVAs. In both conditions, Modality (visual, tactile) and Position (near vs far radial, eye level vs below eye level vertical) were the within-subject factors. In these analyses, only the uncued visual data (as there was no cued condition in the tactile tasks) and data from the 10 subjects completing both visual and tactile tasks were used. The visual and tactile LBE for all subjects are presented in figs 6 (radial) and 7 (vertical). Results of these analyses indicated a significant difference in bisection performance between the two modalities in both the radial [ $F(1,9) = 21.81$ ,  $P = 0.0012$ ] and vertical conditions [ $F(1,9) = 8.39$ ,  $P = 0.018$ ]. The LBE was of equal magnitude in each modality in far peripersonal space but in opposite directions. There was a significant Modality  $\times$  Position interaction [ $F(1,9) = 5.15$ ,  $P = 0.049$ ], and post hoc comparisons using Tukey HSD revealed that visual far radial differed significantly from the tactile far radial LBE ( $P < 0.05$ ). Together, these results indicate that normal subjects err toward the body on tactuomotor but away from the body on visuomotor radial line bisections and that the error is of greatest magnitude in far peripersonal space. Even though no significant vertical tactuomotor LBE was demonstrated, normal subjects also erred in a consistent fashion upwards or away from the body on the vertical visuomotor task.

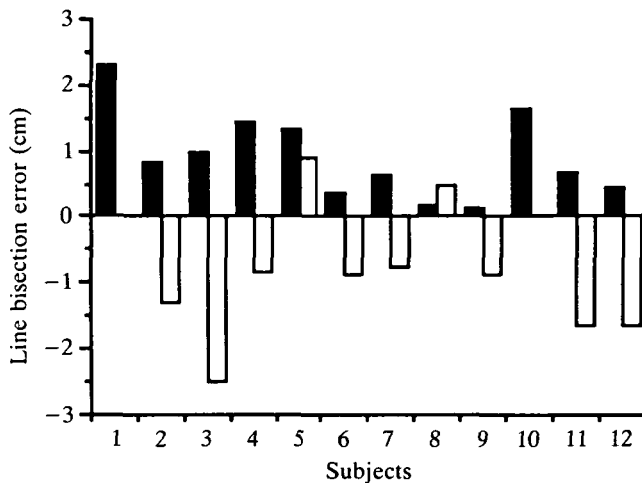


FIG. 6. Mean line bisection error of 12 control subjects for radial stimuli in visuomotor and tactuomotor conditions. (+) error beyond, (-) error near midpoint. Closed bars = visual; open bars = tactile.

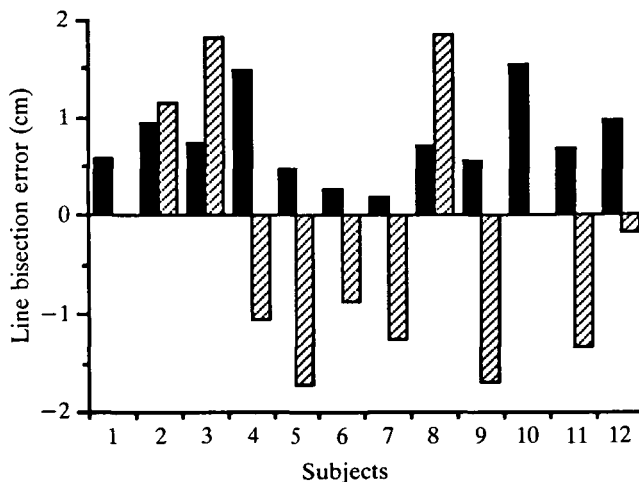


FIG. 7. Mean line bisection error of 12 control subjects for vertical stimuli in visuomotor and tactuomotor conditions. (+) error above, (-) error below midpoint. Closed bars = visual; hatched bars = tactile.

As shown in Table 2, the patient's mean LBE was compared with zero (no LBE) using a one sample, two-tailed *t* test. To control for the effect of multiple *t* tests, the patient data were adjusted with Bonferroni's inequality. The patient repeated the bisection procedure in 12 conditions, and the *P* values reported in the table have been adjusted to  $P \times 12$ . The patient's mean error in each condition was compared with the controls by calculating the number of SDs from the sample mean. The patient misbisected horizontal lines to the right of midline in the visual condition (midline location:



TABLE 2. LINE BISECTION ERROR: PATIENT DATA

Condition	Location	Visual				Tactile			
		Mean	SD	<i>t</i> *	<i>P</i> <sub>c</sub>	Mean	SD	<i>t</i> *	<i>P</i> <sub>c</sub>
Horizontal	Left	1.18	1.59	2.58	n.s.	4.17	1.93	7.46	<0.0002
	Midline	1.88	1.00	6.52	<0.001	—			
	Right	-5.56	1.88	-10.26	<0.0001	-1.54	2.07	-2.58	n.s.
Radial	Near	-2.34	1.49	-0.46**	<0.000001	—			
	Middle	-5.33	2.35	-13.59**	<0.000001	—			
	Far	-7.10	1.95	21.85**	<0.000001	-2.74	2.13	-4.46	<0.02
Vertical	+15†	-5.78	2.08	-9.62	<0.0001	—			
	EL	-5.66	2.20	-8.89	<0.0001	-2.73	3.16	-2.99	n.s.
	-15	-1.04	1.96	-1.84	n.s.	—			
	-30	-2.98	2.23	-4.63	<0.01	—			
	-45	-2.59	2.03	-4.41	<0.02	—			
	-60	-1.18	2.13	-1.91	n.s.	—			

\* One sample, two-tailed *t* test, *df* = 11; \*\* *df* = 35. † cm above (+) or below (-) eye level. (+) values for LBE beyond midpoint (radial), above midpoint (vertical) or the right (horizontal); (-) values for LBE near of midpoint or below midpoint; EL = eye level; *P*<sub>c</sub> = Bonferroni adjustment *P* × 12.

*X* = 1.88 cm, *SD* = 1.00; left hemispace: *X* = 1.18 cm, *SD* = 1.59) but erred to the left for stimuli located in right hemispace (*X* = 5.56, *SD* = 1.88). The LBE was significant at midline (*t* = 6.52, *P* < 0.001) and in right hemispace (*t* = 10.26, *P* < 0.001). His error was greater than 3 *SD* from the control sample mean for stimuli in left hemispace and 15 *SD* in right hemispace, indicating a significant degree of left hemispatial neglect and, at least for stimuli more peripheral in the right hemispatial field, a degree of right hemispatial neglect. He manifested only left hemispatial neglect in the tactuomotor condition (*X* = 4.17, *SD* = 1.93, *P* < 0.001) and only with stimuli in left hemispace.

There is no horizontal plane for separating upper from lower hemispace that is comparable with the midsagittal plane that separates right from left hemispace. When the eyes are in neutral position, the midsagittal plane also separates the right visual field from the left. Therefore we chose eye level as the plane to separate upper from lower hemispace because when the eyes are in neutral position this plane separates upper from lower visual fields. In the visual modality the patient erred consistently below the midpoint of vertical lines (eye level: *X* = 5.66 cm, *SD* = 2.20 cm, *P* < 0.0001; 30 cm below eye level: *X* = 2.98 cm, *SD* = 2.23, *P* < 0.01) and was 15 *SD* from the control mean at eye level. He demonstrated a gradient of response such that LBE was of greatest magnitude for stimuli in upper vertical space as defined by eye level. In the tactuomotor condition, he erred below midpoint (*X* = -2.73, *SD* = 3.16) but with the conservative estimate of significance used (the Bonferroni adjustment), it failed to reach statistical significance (*t* = -2.99, *P* < 0.12).

Finally, the patient consistently misbisected radial lines towards his body at all distances in both visual and tactile modalities. In far peripersonal space in the visual modality he erred by a mean 7.10 cm (*SD* 1.95 cm, *P* < 0.000001) and in the tactile modality by 2.74 cm (*SD* 2.13 cm, *P* < 0.012). In near space in the visual modality he misbisected

radial lines by a mean 2.34 cm (SD 1.49 cm,  $P < 0.000001$ ). He again demonstrated a gradient of response with greater directional errors for more distant stimuli. His LBE was greater than 4 SD from the mean of the controls in both near and far visual conditions and 1.8 SD from the controls in the tactuomotor condition.

## DISCUSSION

The patient described here demonstrated left as well as a degree of right hemispatial neglect on a cancellation task and on line bisection. In addition, he clearly demonstrated extinction of visual stimuli (finger flexion) presented to either superior visual quadrant with simultaneous lower quadrant stimulation. The errors in line cancellation over the top half of the page and in copying figures are analogous to the exploratory and constructional deficits seen in hemispatial neglect and suggest neglect of upper vertical space. When stimuli viewed in the superior visual field were brought near the patient, they were no longer extinguished when presented simultaneously with distant lower visual field stimuli, suggesting neglect of more distant stimuli in the superior visual fields. Retinal image size, however, is a major determinant of depth perception, and this study did not allow us to determine which factor is the most relevant. Near stimuli may also be qualitatively different than far stimuli, and these differences may have accounted for our results. He misbisected vertical lines below and radial lines near midpoint under both visual and tactile control. His errors were consistent and differed significantly from those of the control subjects, suggesting neglect of upper vertical and far peripersonal space.

Because hemianopic patients do not necessarily have neglect and many patients with neglect are not hemianopic, loss of elementary visual function cannot itself account for these deficits in spatial behaviour (Rosenberger, 1974; Ogden, 1985). The patient traced relatively complex figures and had no difficulty in tracing single lines whose extent was limited to the right inferior visual quadrant. His errors and his failure to explore the material were consistently related to the spatial and visual field in which the stimulus was located. Therefore, whereas neglect may have influenced his visual recognition and contributed to his agnosic errors, his visual and perceptual deficits cannot totally account for the line bisection error in upper space. Furthermore, there is no reason to suspect that upper visual field loss would affect line bisection performance more than hemianopia does.

Elementary motor deficits cannot explain the patient's response bias as all testing was done with the right hand. There was only minimal weakness in the right arm in a pattern that cannot be ascribed to his stroke, and limb movement throughout the field where stimuli were located was unrestricted. As he was required to explore the full extent of test lines before tactile bisection, clearly he was able to reach midpoint in all cases. For far radial stimuli the response was always further from the body than the true midpoint of near or midradial lines, indicating that his responses fall short of midpoint for a reason other than restriction of basic motor function. Similarly, in the cued visual bisection task, the identification of figures at the line ends proved that the full extent of the line had been perceived before bisection.

A pathophysiological substrate for vertical neglect has not been entirely elucidated. The patient with lower altitudinal neglect previously reported (Rapcsak *et al.*, 1988) had bilateral parieto-occipital lesions, whereas this patient had bilateral inferior temporo-occipital lesions. As indicated by Rapcsak *et al.* (1988), the upper hemiretina has physiological superiority, and lower visual field stimuli may be more successful in competing for limited attentional capacity. Subjects with a global decrease in visual spatial attention capacity may therefore manifest upper visual inattention because of the comparatively greater saliency of lower visual field stimuli. This alone, however, cannot account for the multimodal nature of vertical neglect in these 2 patients. Electrophysiological studies in monkeys have demonstrated the existence of populations of light-sensitive inferior parietal (IPL) neurons with visual receptive fields confined to upper or lower visual quadrants (Robinson *et al.*, 1978; Motter and Mountcastle, 1981). Some cells with quadrant receptive fields include the fovea, and this class generally discharged to a light stimulus in that quadrant or their activity was further enhanced by saccades towards the light stimulus. Recording from IPL, Robinson *et al.* (1978) demonstrated a preponderance of receptive fields in the lower contralateral visual field, and Motter and Mountcastle (1981) found that cells in IPL, active during hand manipulation, had visual receptive fields confined to the lower quadrants. These cells appear similar in other respects to IPL neurons which are proposed to mediate the direction of attention (Mountcastle, 1976). The paucity of cells with upper quadrant visual receptive fields identified in area 7a suggests that neurons with these 'attentional' properties may be located elsewhere. If so, the inferior temporal visual association cortex might contain such cells.

In addition to his vertical neglect in cancellation, line bisection, and drawing tasks, our patient demonstrated misreaching and consistently erred to the lower right. He not only misreached for targets in upper visual half-fields but also in upper hemispace, irrespective of the retinotopic location of the stimulus. Although he had a mild proprioceptive deficit in the digits of the right hand, there was no dysmetria and he was able to localize his opposite limb accurately in space when blindfolded. A proprioceptive deficit alone should not cause a consistent directional error. Furthermore, this task requires an open-loop movement on the first trial in any location and requires proprioceptive information from both the passively positioned as well as the actively exploring limb (DeJong, 1988). Point localization through the use of proprioceptive information was preserved, therefore misreaching was due to a defect in visually-guided motor behaviour. Holmes (1918, 1919) studied visual localization in patients with bilateral brain injury and found that localization was defective throughout the visual fields. Subsequently, however, cases with defective visual localization restricted to the left or right homonymous visual half-fields were described (Riddoch, 1935; Brain, 1941; Bender and Teuber, 1947). Some patients were consistent in the direction of error (Poppelreuter, 1917) but others were not (Cole *et al.*, 1962; Ratcliff and Davies-Jones, 1972). Subjects with acute lesions characteristically misjudged direction (localization in a frontal plane) and distance (localization in radial direction) but patients with chronic deficits reported by Ratcliff and Davies-Jones (1972) erred only in direction. When

subjects who misreach directed their gaze peripherally so as to fixate peripheral targets, Cole *et al.* (1962) found that the misreaching disappeared. On this basis they concluded that visual disorientation was due to a visual perceptual defect and not to motor guidance per se (reaching). However, Levine *et al.* (1978) reported a case with inaccurate reaching due to a tumour of the superior parietal lobule of the right hemisphere. When the target was fixated but the left hand could not be seen, misreaching persisted. If the subject, however, was allowed to view the left hand as it approached its goal, misreaching disappeared altogether. It appears that the deficit was in the cross-modal integration of proprioceptive and visual information about spatial location.

Unlike these previous cases, our patient mislocalized targets when he was allowed to view his hand both in the upper hemifield and in upper hemispace when the targets above eye level were fixated. Accurate reaching for fixated targets in lower hemispace indicates that the spatial field of the target had an independent influence on visually-guided reaching behaviour. Visual mislocalization was systematically towards the lower right, away from the upper and left spatial fields where he manifested spatial neglect. A similar but horizontal motor bias, termed directional hypokinesia, has been demonstrated in patients with neglect from isolated parietal lobe lesions (Valenstein *et al.*, 1982; Heilman *et al.*, 1985a). Activation of movements towards the neglected field is decreased and manifests as delayed initiation of movement towards neglected space as well as a tendency to fall short of the target (Meador *et al.*, 1988). The pattern of mislocalization demonstrated by this man may be due to directional hypokinesia and a function of the attentional-intentional mechanisms rather than a visual perceptual disturbance per se.

Unlike the patients of Cole *et al.* (1962) and Levine *et al.* (1978) whose mislocalization disappeared for peripheral targets visualized in the central visual field, mislocalization persisted in the central visual field in our case but was less severe. This amelioration of misreaching in central vision could represent the same kind of improvement demonstrated by the previously reported patients and which was believed to support the supposition that visual disorientation is due to a defect in visual perception. The dependence on spatial field of stimulus demonstrated here, however, is characteristic of attentional processes. A hemispace-visual field interaction has been demonstrated for visual extinction whereby stimuli located more peripherally in the visual field are neglected to a greater degree (Rapcsak *et al.*, 1987). In addition, neglect is most profound when visual half-field and head and body hemispace coincide (Bowers *et al.*, 1981). Directional hypokinesia therefore appears to be the most plausible explanation for misreaching in this man. It remains unclear to what extent intentional or visual spatial neglect may account for misreaching and visual disorientation in general, as previous studies have failed to control for hemispace. Directional hypokinesia may actually be a frequent cause of misreaching but would appear to be restricted to cases with systematic directional errors.

Ventre *et al.* (1984) proposed that visual mislocalization and motor aspects of hemispatial neglect are related phenomena, 'the two syndromes overlap and are part of the same functional, if not anatomical, entity'. Further, they proposed that both

syndromes may result from a displacement of an egocentric coordinate system relative to allocentric coordinates derived through sensory input and following a parietal lesion. The results of the current study are consistent with this hypothesis in that visually-guided localization of an external point showed a systematic directional error, whereas no such misreaching was demonstrated towards parts of the patient's own body, where location may be interpreted in terms of egocentric coordinates alone. In the tactile line bisection task, the systematic directional error reappeared, and the results can be interpreted as a displacement of the egocentric coordinate systems guiding the movement of the exploring finger relative to the accurately perceived allocentric coordinates of the midpoint of the rod. The original hypothesis of *Ventre et al.* (1984) may be explained on the basis of a failure of cross-modal integration between retinotopic location and proprioceptive information required for accurate reaching. If the response bias is due to mismatching of egocentric and allocentric coordinates then the same error should exist irrespective of sensory modality. The results of the line bisection test are consistent with the hypothesis but it is not possible to dissociate the effect of the divided attention aspect of the task.

The study of spatial neglect has emphasized the importance of contralateral hemispace in the control of behaviour. *Brain* (1941), however, suggested that the region of extrapersonal space within grasping distance was also of special significance. More recent studies support this contention and suggest that attentional processes mediate this bias. *Leinonen et al.* (1979) and *Leinonen and Nyman* (1979) showed that a population of neurons in area 7b of the parietal cortex of the monkey are multimodal and that their activity is enhanced only by visual targets approaching their cutaneous receptive field or by stationary stimuli within 5–10 cm of it. Most of these light-sensitive cells responded only to movement in a specific direction and did not respond at all if the target was greater than 1 m from the monkey. Area 7b projects in a unidirectional fashion to the posterior bank of the arcuate sulcus (*Chavis and Pandya*, 1976) and *Rizzolatti et al.* (1981a, b) showed that cells in this region have properties analogous to those in area 7b: 54% of the neurons responded consistently to visual stimuli only if less than 10 cm away, and 46% responded to stimuli within arm's reach. They introduced the term peripersonal space to denote this region of extrapersonal space and showed subsequently that postarcuate ablations induce visual and tactile neglect of contralateral pericutaneous stimuli and increased latency in reaching for targets in peripersonal space. Lesions in area 7b likewise result in attentional deficits limited predominantly to contralateral peripersonal space (*Rizzolatti et al.*, 1985).

In the present study we demonstrated that multimodal neglect of events in far peripersonal space occurs in man. The patient misbisected radial lines near midpoint, under either visual or kinaesthetic guidance, and there was a gradient of response whereby his error diminished as stimuli were placed nearer the body. The LBE indicates a deficit in selective attention to far space and a motor bias toward the body, that is, away from the neglected field. The attentional mechanisms in man appear to be organized in terms of proximity to the body in addition to the horizontal and vertical dimension, and focal hemisphere lesions can affect attention-intention to far space preferentially. The

localization of these processes in man is unclear. Area 7 of the monkey cortex is analogous to the inferior parietal lobule of man, but lesions of this region in man have not been shown to be associated with neglect of distal stimuli. It is possible that inferior temporal structures are important in the mediation of attention to far peripersonal and upper vertical space, especially in view of the paucity of light-sensitive inferior parietal neurons with superior quadrantic receptive fields.

Lastly, attentional or intentional biases have been reported previously in normal subjects. For example, normal subjects bisect horizontal lines towards the left (Bowers and Heilman, 1980; Bradshaw *et al.*, 1983). Our control subjects also demonstrated a bias on radial and vertical line bisection. However, unlike the bias reported for horizontal lines, the radial bias was modality-specific such that with the visual task the subjects erred away from their body and with the somaesthetic task they erred towards their body. The visual system is, by virtue of the ability to sense light, specialized for detecting distant stimuli. In contrast, the somaesthetic modality is restricted to the detection of stimuli on or near the body. Perhaps with this specialization there is a modality-specific attentional bias such that attention is preferentially distributed away from the body during visual exploration but is biased towards the body during tactile exploration.

#### ACKNOWLEDGEMENTS

Supported in part by the Medical Research Service of the Veterans Administration and the State of Florida Department of Health and Rehabilitative Services, Division of Aging and Adult Services.

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(Received October 5, 1988. Revised April 18, 1989. Accepted April 26, 1989)

