Leftward search in left unilateral spatial neglect

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Abstract

The authors' previous study with an eye camera revealed that when asked to mark the centre of a line patients with left unilateral spatial neglect persist in fixating a point on its right part and place the subjective midpoint there without searching leftwards. The present study examined the patterns of leftward search of nine patients with left unilateral spatial neglect when they were required to search for the left endpoint of the line after the bisection. The patients could search leftwards beyond the subjective midpoint to place the mark at the subjective left endpoint. The initial fixation in this search always fell near the point located to the left of the subjective midpoint by the distance between the subjective midpoint and the right endpoint of the line. In patients with severe neglect the search further to the left of this point was laborious and fell short of the true left endpoint in about 80% of the trials. Our results suggest that when asked to bisect a line patients with left unilateral spatial neglect subjectively see the line as it extends equally to either side of the point where they are going to mark the subjective midpoint.

The line bisection test has long been used for a sensitive measure of unilateral spatial neglect.^{1,2} Patients with left unilateral spatial neglect place the subjective midpoint to the right of the true centre. Recently, we elucidated the visuospatial processes of line bisection by observing the eye fixation pattern with an eye camera.³ Once the patients with left unilateral spatial neglect fixated a certain point on the right part of a line they persisted with this point and marked the subjective midpoint there. Leftward search never occurred. As the fixation point recorded by the eye camera corresponds closely to the macula of the retina, the visual field on the left side of the fixation point was considered equivalent to the impaired field due to accompanying left homonymous hemianopia or left-sided visual extinction.⁴ Thus the lack of leftward search beyond the subjective midpoint indicated that the subjective midpoint was marked, not at the centre of the line segment perceived in the seeing right visual field, but at the leftmost point of it, although the patients understood the meaning of line bisection. We interpreted these results to mean that patients with left unilateral spatial neglect

subjectively see the line as it extends equally to either side of the point where they are going to mark the subjective midpoint. This interpretation has been discussed in detail in our previous paper.³

The present study examined the pattern of leftward search when patients with left unilateral spatial neglect were asked to mark the left endpoint of the line after the bisection of it. We predicted that the visuospatial process during line bisection should be reflected in the pattern of search for the left endpoint of the line.

Methods

Subjects

The subjects were nine right handed patients with left unilateral spatial neglect after a right hemisphere stroke. All subjects were examined on the copying of a daisy,⁵ the cancellation test,⁶ and the line bisection test.³ The degree of neglect in each test was rated as severe, moderate, mild, or none according to the scales of Ishiai *et al.*³ Cases 1 to 6 showed severe left unilateral spatial neglect when copying a daisy and severe or moderate neglect in the two other tests. In cases 7 and 8 neglect was moderate or mild in the three tests. Case 9 showed mild neglect in the copying and the line bisection test but did not leave out any line in the cancellation test. Thus we classified the subjects into two groups; cases 1 to 6 as the severe neglect group and cases 7 to 9 as the mild to moderate neglect group. The lesions were determined by CT scans. Cases 4 and 9 had haemorrhages and the seven other cases had infarcts. Confrontation testing revealed a left homonymous hemianopia in cases 1 to 8. Case 9 showed a left inferior quadrantanopia. No subject showed any obvious deviation of the eyes or head toward the right side. The range of eye movements was not restricted on routine neurological examination. The age range was 46 to 77 years (mean 60). All subjects were examined at least one month after the onset of symptoms. Table 1 summarises the clinical data and the lesion sites.

Procedure

A line 200 mm or 150 mm long drawn horizontally across the centre of B5 (182 × 257 mm) plain paper was presented to the subjects by the examiner who sat facing them. They were instructed to mark the centre of the line which was so placed that the true midpoint was in line with the sagittal midplane of the subject's body. They then had to search for and mark the

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Table 1 Clinical data and lesion sites of patients

Case	Age (years)	Sex	Duration after onset (months)	USN*			Lesion
				CO	CA	LB	
1	64	M	1	+++	+++	+++	FTPO
2	58	M	4.5	+++	+++	+++	FTPO
3	58	M	3.5	+++	++	+++	FTPO
4	73	F	9	+++	++	+++	DFTP
5	49	M	3.5	+++	++	+++	FTPO
6	66	M	10	+++	++	++	FTP
7	77	M	3.5	++	++	+	FTP
8	49	F	5	+	+	++	FTP
9	46	M	6	+	-	+	DFTP

*USN = Unilateral spatial neglect; - none, + mild, ++ moderate, +++ severe; CO = copying daisy; CA = cancellation test; LB = line bisection test; F = frontal; T = temporal; P = parietal; O = occipital; D = deep lesion.

point which they believed to be the left endpoint of the line. We termed their mark the "subjective left endpoint". They received practice trials before starting to ensure that the procedure was understood. Each subject performed the task three times for both 200 mm and 150 mm lines with the right hand. These two lengths of lines were presented in a pseudorandomised order. In these trials, we presented the test sheets without speaking to minimise the possibility that the verbal instruction might activate the left hemisphere and cause an attentional shift.⁷

We recorded the eye fixation pattern and the marking process throughout the tasks by means of an eye camera (Eye Mark Recorder type V; NAC Inc). The head unit of this apparatus, which includes a scene camera as well as the eye camera, is only 830 g in weight and is connected to the control unit by flexible cables. Head movement was possible during the task. The subjects could perform the tasks under near natural conditions. The corneal reflection detected by the eye camera is transduced electronically in to the eye mark and then superimposed on the picture from the scene camera. The movements of the eye mark are adjusted so that when the subject looks at known points in the visual scene the mark lies over these points in the combined eye-scene picture. We recorded the combined eye-scene picture with a video tape recorder at a speed of 30 frames/s.

Data analysis

The fixation point always moved on the line during the task which included both the line bisection and the marking of the subjective left endpoint. Lateral movement of the fixation point on the line was analysed, reproducing the VTR recording of the eye-scene picture frame-by-frame.

Results

Eye fixation pattern during line bisection

Figure 1 shows examples of the eye fixation patterns from the first fixation on the line to the start of marking the subjective left endpoint for 200 mm lines. The left unshadowed parts of the graphs correspond to the period of line bisection—that is, the process from the first fixation on the line to the start of marking the subjective midpoint. When the line was presented, the subjects could find it without

difficulty and fixated a certain point on the right part of the line. They persisted with this point and marked the subjective midpoint there. Although rightward search was occasionally interspersed with the dominant fixation, leftward search never occurred. All the subjects showed such an eye fixation pattern during line bisection in all the trials for both 200 mm and 150 mm lines.

Search for the left endpoint

In the second part of the task after line bisection, when the subjects were required to search for the left endpoint of the line, all of them began to search leftwards. As the manual marking of the subjective midpoint took a few seconds in some patients, the leftward search occasionally started within the duration of marking the subjective midpoint (figure 1, shadowed area). The initial fixation in this leftward search always fell near the point located to the left of the subjective midpoint by the distance between the subjective midpoint and the right endpoint of the line (figure 1). This point corresponds to the left endpoint of the "subjective line", which the subjects were expected to see subjectively as it extends equally to either side of the subjective midpoint during line bisection. Figure 2 illustrates the

Figure 1 Examples of eye fixation patterns throughout task. Shaded area shows duration of marking subjective midpoint. Initial fixation in search for left endpoint is circled. R, C, and L indicate right endpoint, centre, and left endpoint of line; ▶ and ◀ indicate subjective midpoint and subjective left endpoint; a: type 1 pattern of leftward search (case 1); b: type 2 with stepwise saccadic movements (case 7); type 2 with slow pursuit-like movements (case 2).

Figure 2 Relation of initial fixation in leftward search to subjective line. Arrowheads and circled point correspond to those of figure 1; a, b, and c correspond to pattern type (see figure 1).

relation of the initial fixation in the leftward search to the subjective line.

The patterns of leftward search were classified into two types. Type 1 (figure 1A, 2A): the subjective left endpoint was marked at the point of the initial fixation in the leftward search and no further search occurred. Type 2 (fig 1B, C and 2B, C): in the course of the leftward search, the fixation point first stopped near the left endpoint of the subjective line. Further leftward search, however, was made beyond there. This search consisted of a few stepwise saccadic movements (figure 1B) or slow pursuit-like movements (figure 1C) or both of the fixation points. The subjective left endpoint was marked at the leftmost point of this search. The search did not always reach the true left endpoint. We defined that a fixation was made when the fixation points on six or more serial frames of VTR were located in the same position. Six frames correspond to a duration of 200 ms, somewhat shorter than the lower limit of the duration of a fixation (250 ms) proposed by Yarbus.⁸ The duration 200 ms is equal to the mean latency of the primary saccade without prediction in normal subjects.⁹ The mean durations of the initial fixation were 1356 ms (SD 548) for type 1 pattern of leftward search and 322 ms (SD 166) for type 2 pattern. The leftward search before the initial fixation was made up of one saccadic movement in 93% (50/54) of all the trials. In

the remaining 7%, it was interrupted by a small step where the fixation point stayed at the same position through less than six frames.

Location of the initial fixation in the leftward search

We compared the length of the line segment between the initial fixation in the leftward search and the right endpoint of the line (figure 2,*) with that of the subjective line. Figure 3 shows that there is a close correlation between these two lengths for both 200 mm and 150 mm lines. The correspondence is good. Some patients marked the subjective midpoint at a wide variety of positions on lines of the same length. Even in such cases, the length of the line segment between the initial fixation in the leftward search and the right endpoint tended to correspond to the length of the subjective line. The mean lengths of the subjective line during the bisection of 200 mm and 150 mm lines were 104.5 mm (SD 45.6) and 96.7 mm (SD 27.0), respectively, and those of the line segment between the initial fixation in the leftward search and the right endpoint of the line 94.1 mm (SD 40.0) and 93.0 mm (SD 33.4). These mean lengths did not significantly differ between 200 mm and 150 mm lines (Student *t* test, *t* = 0.76 and 0.11).

Severity of neglect and the search for the left endpoint

Table 2 shows the locations of the subjective left endpoint and the subjective midpoint with the type of search in each trial for all the patients. Type 1 pattern of leftward search was observed in two of the severe neglect group patients. Case 1 showed the type 1 pattern in two of three trials for both 200 mm and 150 mm lines and case 3 in two of three trials only for 200 mm lines. Type 2 pattern of leftward search was found in all subjects. The type 2 pattern with typical slow pursuit-like movements of the fixation point (figure 1C), however, was found only in the three trials for 200 mm lines performed by case 2 whose neglect was severe in all the three tests of neglect. The latencies for these trials were 29.8, 24.2 and 20.2 s, which were much longer than the mean latency of all the other 50 trials (5.78 s, SD 2.67). Such long latencies for the task were thus rare in patients with left unilateral spatial neglect. Rather short latencies were expected to be common because, in the previous study,³ we had observed that neglect patients bisected lines quickly. Each of the severe neglect group subjects (cases 1 to 6) marked the subjective left endpoint to the right of the true one in at least two of six trials. By contrast, the mild to moderate neglect group subjects (cases 7 to 9) could find the true left endpoint and marked it there in all the trials. The subjective left endpoint was marked at the true left endpoint in 11 of 27 trials for 200 mm lines and 14 of 27 trials for 150 mm lines. We designated these trials as "reached" ones and the remaining trials as "unreached" ones. The mean percentage deviations¹ of the subjective midpoint in reached and unreached trials for 200 mm lines were 29.3 (SD 16.0) and 60.4 (SD

Figure 3 Lengths of subjective line and line segment between initial fixation in leftward search and right endpoint (figure 2,*); solid line indicates ideal correspondence between them ($y=x$); dashed line shows regression line; a: 200 mm lines ($y=6.77+0.84x$, $r^2=0.91$); b: 150 mm lines ($y=-15.3+1.12x$, $r^2=0.82$).

Table 2 Lengths (mm) between the true left endpoint and subjective left endpoint/subjective midpoint for all three trials per line length (patterns of leftward search)

Case	200 mm Line			150 mm Line		
	1	2	3	1	2	3
1	154/178 (1)	119/171 (2)	120/161 (1)	102/124 (1)	72/129 (2)	76/114 (1)
2	37/178 (2)	91/180 (2)	0/157 (2)	89/124 (2)	52/108 (2)	21/96 (2)
3	122/165 (1)	121/172 (2)	128/162 (1)	55/106 (2)	57/97 (2)	65/109 (2)
4	118/167 (2)	82/169 (2)	48/153 (2)	20/115 (2)	51/116 (2)	36/105 (2)
5	0/160 (2)	68/162 (2)	50/165 (2)	0/108 (2)	0/101 (2)	0/115 (2)
6	41/129 (2)	58/133 (2)	56/122 (2)	23/81 (2)	0/84 (2)	0/101 (2)
7	0/125 (2)	0/130 (2)	0/127 (2)	0/88 (2)	0/95 (2)	0/91 (2)
8	0/119 (2)	0/110 (2)	0/133 (2)	0/89 (2)	0/91 (2)	0/97 (2)
9	0/121 (2)	0/128 (2)	0/113 (2)	0/83 (2)	0/92 (2)	0/85 (2)

17.7) respectively, and those for 150 mm lines 25.8 (SD 12.5) and 46.0 (SD 17.4). The mean percentage deviations of the unreached trials were significantly larger than those of the reached trials for both lengths (Student *t* test, $t = 4.67$, $p < 0.0001$ and $t = 3.49$, $p < 0.002$).

Discussion

When a line is presented, patients with left unilateral spatial neglect fixate a certain point on the right part of it. They persist with this point and mark the subjective midpoint there. It may be expected that they would fixate the right endpoint of the line initially upon presentation, but such a fixation was not observed. In the present study, the examiner sat facing the subject across a table and presented lines. This experimental condition seems to be the main reason why they did not need to start searching from the right endpoint. Leftward search never occurred spontaneously during line bisection, although rightward search was occasionally interspersed with the dominant fixation. Such an eye fixation pattern during line bisection was observed in all the trials for each subject. This result confirmed the observations in our previous study.³ The lack of leftward search during line bisection may be a manifestation of attentional disorder^{7,10-12} or hemispatial and directional hypokinesia.¹³⁻¹⁵ The visual field on the left side of the fixation point was impaired due to accompanying left homonymous hemianopia or left sided visual extinction. Thus the lack of leftward search beyond the subjective midpoint indicated that the subjective midpoint was marked, not at the centre of the line segment perceived in the seeing right visual field, but at the leftmost point of it.

In this study we have shown that all the patients made leftward searches in the second part of the task when they were required to search for the left endpoint of the line after line bisection. This suggests that patients with left unilateral spatial neglect have the ability to search leftwards beyond the subjective midpoint when they are asked to do so. The initial fixation in the leftward search always fell near the point which was located to the left of the subjective midpoint by the distance between the subjective midpoint and the right endpoint of the line. This point corresponds to the left endpoint of the subjective line which the subjects were expected to see during line bisection. Some patients bisected lines of the same length with varied deviations. In each of such

trials, the initial fixation in the leftward search was found to fall near the left endpoint of the subjective line. These results (and those of our previous work³) suggest that when asked to bisect a line, patients with left unilateral spatial neglect subjectively see the line as it extends equally to either side of the point where they are going to mark the subjective midpoint. Patients with left unilateral spatial neglect, however, can appreciate the deviation of the subjective midpoint when they see the whole line in the right visual field.³ They might search leftwards until the part of the line perceived in the right visual field was divided into two equal parts by the subjective midpoint. If the search was guided by such an adjustment, it would be slower and more stepwise before reaching the point located to the left of the subjective midpoint by the distance between the subjective midpoint and the right endpoint. As the search to this point was almost always made up of one saccadic movement, this explanation seems unlikely.

Recently, several papers¹⁶⁻¹⁸ have reported that there are diverse patterns of behaviour in line bisection as a function of different line lengths. Bisiach *et al*¹⁶ tried to interpret these diverse patterns, focusing on the left endpoint of the "represented line" which was deduced from the right endpoint of the line and the subjective midpoint just like the subjective line in the present study. They considered that some patients adjusted the subjective midpoint to the centre of the represented line. Our results suggests that the line which patients with left unilateral spatial neglect subjectively see during line bisection is simply based on the point where they persist in fixating and mark the subjective midpoint. Therefore it seems difficult to consider that the representational mechanism determines where to mark the subjective midpoint on the line. The patterns of leftward search were classified into two types. In type 1, the subject left endpoint was marked at the point of the initial fixation in the leftward search and no further search occurred. In type 2, further leftward search occurred beyond the point of the initial fixation, although this search did not always reach the true left endpoint of the line. The leftward search beyond the left endpoint of the subjective line tended to be laborious or fall short of the true left endpoint when left unilateral spatial neglect was severe. Kartounis and Warrington¹⁹ reported that the performance of patients with unilateral spatial neglect sometimes improves when stimuli are interactive or continuous or both. In the case of type 2 search, we consider that the patients searched by tracing the left limb of the line further to the left of the subjective line.

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