LINE BISECTION ERRORS IN VISUAL NEGLECT : MISGUIDED ACTION OR SIZE DISTORTION'?

A. D. MILNER,*† M. HARVEY,†§ R. C. ROBERTS[†] and S. V. FORSTER[†]

+Department of Psychology, University of St Andrews ; and'+ Department of Neurology, University of Dundee. Scotland, U.K.

(Received 21 May 1992; accepted 17 August 1992)

Abstract--The rightward line bisection errors made by patients with visuospatial neglect can be explained as due to a spatially misdirected response, which would he predicted on either of two accounts . An alternative view, however, is that such patients actually misperceive the left half of a horizontal line as being shorter than the right half. We have tested this possibility directly in three neglect patients, by giving them prehisected lines : they were found to judge a central transection mark as lying nearer to the left end of the lines . We were also able to test one of the patients on a series of size comparisons using compater-generated patterns . She was found tojudge horizontal lines as shorter in the left half of visual space than in the right. This was also true for comparisons of the areas of nonsense figures . However she did not make such constant errors when comparing the lengths of vertical lines . It is suggested that an attentional deficit in left hentispace may result in the underestimation of horizontal extent. This would act in combination with misdirected reaching to determine the magnitude of line bisection errors .

INTRODUCTION

RIGHT-HEMISPHERE DAMAGED PATIENTS With Spatial neglect frequently make rightward errors when asked to bisect a line at its centre $[8, 15]$. HEILMAN and VALENSTEIN $[8]$ made the proposal some years ago that such errors might be due to constant errors in directing an action in egocentric space . rather than to errors of spatial perception or attention . They attributed these errors in turn to an underactivation of right-hemisphere premotor systems which would initiate action in a leftward direction: thus intended acts would be biased by a predominance of rightward vectors . HEILMAN and his colleagues subsequently demonstrated this phenomenon of "direction hypokinesia" directly [9] .

Recently, a different model has been proposed that could be generalized such as to lead to similar predictions. HALLIGAN and MARSHALL [6] examined visuospatial localization in a patient with severe visual neglect . In the critical task condition, the subject was required to judge the spatial location of an arrow on a TV screen, the arrow being located either at the bottom or top of the screen, pointing inwards . The subject made her location judgements by indicating verbally which of an array of 15 numbers, on the opposite edge of the screen, the arrow was aligned with. It was found that the patient (P.P.) erred rightwards in these

^{*}Address for correspondence : A . I) . Milner, Psychological Laboratory, University of St Andrews . St Andrews . Scotland KY16 9JU U.K.

[§]Formerly M. Brechmann.

judgements, with an average error of about 1 cm. However the errors of judged location tended to be greater the nearer the arrow was presented to the left edge of the screen (up to an average of 1 .75 cm), and less when it was near the right edge of the screen (declining to zero) . The authors liken their results to the compression of a spring from left to right: it is as if the coordinates of P.P.'s subjective space were pushed over to the right but uniformly 'shrunk' at the same time, thus maintaining Euclidean properties of equal spacing.

A simple generalization of this model could provide a ready account of the line bisection behaviour of neglect patients . Visualize the horizontal dimension of space as a compression spring, and a horizontal line as equivalent to (say) 4 coils of the spring. If then subjective space is *uniformly* compressed in a neglect patient, a 20 cm horizontal line might appear to be (say) 17 cm long, irrespective of where it appears in objective space . However, if the compression is toward a fixed point on the right, as hypothesized [6], then the horizontal line should appear to be shifted as a whole rightwards in space. This would predict a corresponding rightward error of the hand in moving to bisect the line, just as is assumed to occur in directional hypokinesia, thus yielding the well-known bisection error . There is good direct evidence that right-hemisphere damaged patients, even after recovery from overt neglect, do indeed project the arm along rightwardly directed trajectories [4, 7].

Interestingly, this extension of the space-compression model would also predict a variation in the line bisection error as a function of line location . Although all lines should appear subjectively shifted rightwards in location, a line placed on the patient's right should be shifted rather less, but one to the left shifted more . than a central line . Thus the arm should he misdirected more in respect of lines placed in left hemispace and less for lines in right hemispacc . Such a spatial variation of bisection errors has indeed been reported several times [8, 13 . 15] .

An alternative kind of spatial misperception that might be present in neglect patients was proposed by M[LNER [11] . It was suggested that there might be a distortion of the subjective space of a neglect patient that was non-Euclidean. That is, subjective space might be compressed, but progressively more so in more leftward parts of space . According to this view, the space occupied by the left half of a line would literally appear shorter to a neglect patient than the right half: therefore bisection would tend to be performed in a rightward direction . This idea would predict rightward bisection errors, but can only account for the increased errors in left space and the lesser ones in right space if it is assumed that the gradient of distortion is steeper in the leftward parts of ego-space than in the rightward parts $[11]$.

The data of HALLIGAN and MARSHALL $[6]$ may be regarded as a direct test of this strong version of Milner's hypothesis . For each of 15 locations . 1 cm apart, their patient was asked to indicate the arrow's subjective position . According to MILNER [11], the subjective spacing between adjacent pairs of these 15 points should increase as one passes from left to right . The actual mean spacing of P.P.'s judgements however, show no trend for such an increase. Therefore the distortion of P.P.'s subjective space appears to be more closely modelled by a uniform compression that maintains Euclidean geometry, as HALLIGAN and MARSHALL $[6]$ argued.

It could be, however, that the task used by HALLIGAN and MARSHALL might underestimate abnormalities in subjective spatial relationships in neglect, since changes in the perception of the arrow's location might he matched by similar changes in the perceived locations of the numbers used to code the response . In addition, there is a necessary ceiling effect on judgements near the right edge of the screen, since large rightward errors would have hit or exceeded the edge. In any case, although MILNER's suggestion may lack generality, it

might nonetheless have application within a more constrained context . In particular, it might apply to the perceived sizes of objects rather than to the distances between them. This weak version of the model, positing only a distortion of size within the visual field, could peacefully coexist with the uniform compression of space proposed by HALLIGAN and MARSHALL. GAINOTTI and TIACCI [3] showed several years ago that in many right-hemisphere damaged patients, visual shapes tended to be under-estimated in size when compared with similar shapes shown on the right. They attributed this to the presence of patients with neglect in their group, and presented evidence to support this contention . Their data thus lend support to the present view.

Neither the directional limb hypokinesia theory nor the uniform compression of space theory would predict that a given line would appear of different length in different parts of visual space, nor that its true midpoint would appear to be shifted from centre . Instead, rightward bisection errors are explained on these theories as resulting from a spatial misdirection of the act of bisecting . One simple test of such accounts is therefore to present a pre-bisected line $\lceil 10, 12, 14 \rceil$: in particular to use the so-called "Landmark task" $\lceil 12 \rceil$. When the transection (the "landmark") is at the objective midpoint of a line, then on either the uniform-compression or the hypokinesia theory, a neglect patient should see the mark veridically as being at the midpoint . If, however, the patient literally sees the left half of the line as shorter than its right half [11, 13], then a central transection should be judged as nearer to the left end of the line. On the additional assumption [11] that the distortion of size scaling might change more steeply in left hemispace . the errors in landmark judgements should be more pronounced there than in central or right space .

In the present paper we describe three patients, each with a clinically manifest neglect syndrome, who presented typical line bisection errors which varied in the usual way when the lines were presented in different parts of visual space . We then report data on the performance of these patients on the landmark task, including an examination of the effects of spatial location . Finally, we describe a confirmatory investigation of GAINOTTI and TIACCrs [3] perceptual mismatching phenomenon in one of our patients . Unfortunately the other two neglect patients died before these perceptual matching tasks could be administered to them.

METHODS

Potions

Three right-handed patients were recruited who had sustained right hemisphere stroke and who performed outside normal limits on a subset of the Behavioural Inattention Test (BIT) [16]. Scores were derived from the following suhtests : line crossing, letter- and star-cancellation, figure copying, line bisection and representational drawing. The cut-off for normal performance is a summed score of 130/146. Brief details of the three patients follow.

M .J . is a 61-year-old woman who had sustained a right hemisphere stroke ⁸ months prior to testing . A CT scan performed 10 days post-onset showed a patchy low attenuation in the right mid/anterior white matter. The patient had a left hemiplegia and also a left homonymous hemianopia. Her BIT score was 30/146 with 100% omissions in contralesional and central space for all cancellation tasks; in fact only stimuli on the extreme right of the page were
attended to

attended to . ^I .H . was a 67-year-old woman who had sustained right hemisphere damage 6 months prior to testing . ('I-scan evidence at 7 months post-onset indicated an extensive right paicto-occipital infarct . The patient had a left hemiplegia but no reported visual field deficit. Her BIT score was 125/146 with all omissions occurring in contralesional space.

L .H . was a 76-year-old woman who sustained a right hemisphere stroke 6 months prior to testing . She showed a left hemiplegia and a left homonymous hemianopia and was also dysarthric . CT-scan evidence was not available . but the history and all clinical signs were consistent with right-sided stroke. Her BIT score was 48/146 with 100% omissions in contralesional and central space : only stimuli on the extreme right of the page were attended to .

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Twelve right hemisphere stroke patients (six male, six female) ranging in age from 57 to 76 years (mean -65.8, $S.D. = 6.2$) without any evidence of neglect at the time of testing, acted as controls. All were right-handed, and all had CT-scan evidence of unilateral right hemisphere damage only, there was no attempt to select for lesion location within the right hemisphere.

Line bisection

Materials. Twelve lines of 20 cm length and 1.5 mm width were presented for bisection. They were placed horizontally and centrally on a sheet of A4 paper . The lines were equally divided between ones cued with a letter placed at left end, right end, both ends, or at neither end (cf. Ref. [12]).

Procedure. Patients were seated at a table opposite the experimenter, who ensured that their body position remained constant throughout the testing. Patients were instructed to bisect the line centrally as accurately as possible, using the right hand, proceeding line by line through the sheet. After each transection, that line was covered with a card in order to prevent comparison of the present response with previous bisections . Head and eye movements were not restricted in any way . For each patient t he set of lines was presented once in each of three spatial locations (left, right or central to the subject's body midline). The order of locations was counterbalanced between patients according to a 3×3 Latin square. In the central condition the viewing distance of the line that was to be hisected was approximately 45 cm. In the left and right hemispace presentations the sheet was located such that the centre of each Iine lay at a distance of 30 cm from the sagittal body midline .

Errors in line bisection were measured to the nearest millimetreand averaged [or each spatial location . Errors to the right of the midpoint were given a positive value and those to the left a negative value .

Landmark testing

In the landmark test, patients were not asked to bisect a line, but instead were presented with lines that were already transected. The patients had to make a forced-choice manual judgement as to whether each line was transected nearer to its right end or its left end.

Materials. Again lines were of 20 cm length and 1.5 mm width, and were drawn horizontally and centrally on sheets of A4 paper (used sideways), one line per sheet. Each line had been pre-transected at right angles with a "landmark'line 10 mm in length and I mm in width -The viewing distance and line locations were the same as in the line bisection task .

A total of 22 lines was presented, of which 10 were asymmetrically pre-transected, at 1, 2, 3, 4 or 5 mm to the right or the left of the true centre. These 10 asymmetrical stimuli were ancued, and served as fillers intended to encourage the impression that all 22 lines might be asymmetrically bisected . The remaining 12 lines were in fact transected at the midpoint, and equal numbers were cued at left, right, both or neither end (cf. Ref. [12]). The effects of cueing are not reported here .

Procedure. Again patients were seated at a table opposite the experimenter, who ensured that their body position remained constant throughout the experiment. They were falsely informed that none of the transections were placed at the exact centre of a line. They were required to point to the end of the line that appeared closer to the transection. Patients were forced to make a left/right choice even if it was necessary to guess: no other response was permitted. The set of trials was presented once in each of three spatial locutions (left, right oreentral) . Orderof presentation was counterbalanced between patients in a Latin-square fashion. Again head and eye movements were in no way restricted .

For the lines pretransected at the midpoint, the number of *left*-end responses provides an index of the extent to which each patient sees the left half of the line as shorter than the right. The left-side bias for the three neglect patients may be compared against the average for the 12 control patients, separately for each spatial condition.

Perceptual matching

In order to test directly the hypothesis that patients with clinical neglect may experience a distortion of their perception of items in the visual field, a series of matching tasks was devised. These were performed by the patient M.J. and by all of the control subjects.

Procedure. Patients were scated centrally at a distance of approximately 60 cm in front of a 14-in. long-persistence colour graphics monitor. Pairs of computer-generated patterns (constructed using a Pluto graphics system: IO Research Ltd) were presented in a pseudorandom series, in order to explore the point of subjective equality between patterns placed in left and right visual hemispace . The patterns displayed were either identical or differed in length . width, size or other dimensions, along a scale ranging from just-noticeable to large and obvious differences. The patients were falsely informed that none of the pairs were identical and were asked to indicate manually on each trial (in the presently reported data) which one of the two patterns they thought to be longer, wider, or larger, as appropriate . Up-down comparisons were used as a control condition and randomly interspersed with left right comparisons. The patients responded by pressing one of the four keyboard "arrow" keys, designated so as to be compatible with the four possible directional judgements, 'I'hese keys were placed centrally in front of the monitor screen and the rest of the keyboard was covered with cardboard to eliminate interference from other keys. Patients were forced to make a left right or up down choice even if it was necessary to guess : no orhcr response was permitted-'I'here was no time constraint and the patterns remained visible until a permitted key was pressed (either the left or right key for laterally presented patterns or one of the up down keys for the vertical pairs) . Once a permitted key was pressed, the next patterns appeared after an interstinmlus interval of one second . All patients responded with the right hand.

If a patient perceives the rightward of two patterns as being larger, he or she should press the rightward arrow key rather than the left. However the same tendency would be expected if the patient was showing a lateralized (rightward) response bias or "directional hypokinesia" . To tease out the effect of such a contaminating response bias, patients were tested twice, under opposing response instructions . On one occasion they were asked to judge which stimulus appeared larger or longer, and on the other to indicate the stimulus that appeared smaller or shorter. Patients with a lateralized response bias should tend to show rightward manual responses independently of these different instructions, whereas patients with a true perceptual bias should respond rightwards on the 'larger' instructions and leftwards on the "smaller" instructions .

Materials. Seven different sets of patterns were created. They included horizontal lines, vertical lines, nonsense figures, gratings of different spatial frequency, random dots with differing density, oblique arrays of differing orientation and grey-level patches with differing brightness levels. Only the results on the lines and nonsense figures are directly relevant to the issue addressed in the present paper : the other data will be reported elsewhere.

For each stimulus type, a prototype was created, and on all trials this was presented in one half of the screen Ileft, right, top or bottom), in combination with either an identical pattern or a reduced size pattern derived from it, in the other half of the screen . Each stimulus was located with its centre at a distance of 4 .5 cm, up, down, right or left from the centre of the screen .

The prototype *horizontal line* was of 4 cm length and 0.5 cm width and presented as an outline rectangle. Ten shorter lines were derived from it, each having the same width but varying in length from 95 to 50% of the prototype, in steps of 5% . All the possible combinations of these 10 lines with the prototype, plus one identical pairing, in left right and up down orientations, produced 42 pairings, which were presented in pseudorandom order. Similarly, vertical lines of4 cm length and 0 .5 cm width, and smaller patterns derived from them, formed another set of 42 pairs . In the first test session, with both sets of stimuli, patients were instructed to press the key that indicated the longer line, and in the second session the key that indicated the shorter line .

The prototype of the nonsense figure was again drawn as an outline, and consisted or an irregular 11-sided polygon covering an area of 16 cm². The area of the 10 comparison patterns ranged from 95% of the prototype down to 50%, again yielding a total of42 pairs . Patients were instructed to press the key corresponding to the larger (or in the other session the smaller) figure . and the control group and the second was solvent when the control due intervals and outline, and consisted or an irregular 11-sided
polygon covering an area of 16 cm³. The area of the 10 comparison patterns ranged from 9

To prevent interference between the opposing instructions, the two sessions of testing were separated by a minimum time interval of 1 week. Order of instruction presentation (longer/larger vs shorter/smaller) was balanced across patients within the control group. For M.J. the order was "longer/larger" followed by "shorter/small

RESULTS

Line bisection

The mean error scores of the three neglect patients indicate a predominance of large rightward bisection errors (see Table 1) . To examine the effect of spatial location, a one-way ANOVA was performed, separately for each of the three patients . All three showed highly significant effects of space $[F(2, 33) = 19.85, P < 0.001; F(2, 33) = 18.29, P < 0.001;$ $F(2, 33) = 5.97, P < 0.01$. For patients M.J. and I.H., *post-hoc* analyses revealed significant differences (Newman-Kculs: $P < 0.05$) between left and right hemispace (I.H. indeed showed leftward errors in right hemispace) and between central and right, but not between central and left hemispace . L .H . however showed significant differences between central and right hemispace and central and left hemispace, but not between left and right . The averaged errors of the control group proved to be small in all spatial conditions (see Table I), though with considerable intersubject variation.

Landmark judgements

Figure 1 shows the proportion of left or right judgemental responses of each neglect patient when presented with centrally transected lines . It is evident that all three neglect patients made predominantly leftward judgements. This bias proved to be significant in all three spatial conditions for patients M.J. and L.H. and in the left hemispace for patient I.H. (Binomial Test, $P < 0.05$). This indicates that they perceived the left half of the lines as shorter

Table 1. Mean errors (mm) made on a bisection task presented in three different spatial conditions. Positive values indicate rightward deviations. negative, leftward. Data are given for three neglect patients and for a group of 12 right-hemisphere controls

Patient	Left space	Centre	Right space
MI.	-26.0	$+33.7$	$+6.5$
LH.	-10.0	$+8.7$	-9.0
L.H.	$+25.1$	$+3.8$	$+19.6$
Mean	$+20.4$	$+15.4$	$+5.7$
Controls	-0.85	-1.42	2.73
(S.D.)	(6.6)	(6.6)	(8.1)

than the right . There was a tendency for a greater leftward bias in response to lines placed in left than right hemispace in M.J. and I.H., while a ceiling effect obscured any possible difference in L.H.

Fig. 1. Proportion of left and right responses made in the landmark test, in three different spatial conditions (12 trials per location) . Data are given for three neglect patients and for a group of ¹² righthemisphere control patients . A response to a given side indicates that the subject sees that end of the line as closer to the centrally-located "landmark"

In contrast, no leftward perceptual bias is apparent in the data of the control patients, who showed no significant departure from a 50/50 division of their choices when considered as a group (one-sample i -test). They also responded similarly across the three hemispatial conditions (one-way ANOVA).

The tendency of the three neglect patients to judge the left part ofa pre-transected line to be shorter than the right extended even to lines that were not centrally bisected . With lines pretransected to the left of centre . they responded correctly (to the left) at levels averaging from 93 to 100% . However, with lines pre-transected to the right, errors (responses to the left) ranged from 73 (I.H.) to 100% errors (M.J. and L.H.), i.e. they still tended to point to the left end of lines. Evidently even a line marked 5 mm to the right of centre appeared to these three patients as marked to the left of centre. In I.H., these errors with non-centrally transected lines tended to be more frequent in left hemispace than in right.

In contrast, the control patients made few errors with these asymmetrically marked lines . They further showed no significant difference between the numbers of errors made with rightwardly vs leftwardly transected lines $\lceil t(11) = 1.48 \rceil$, and indeed made no errors at all when the landmark was more than 3 mm to the right of centre.

Perceptual marching task

Scoring procedure. The perceptual matching task was analysed to yield independent measures of response bias and perceptual bias . As the three different stimulus series were not matched for discrimination difficulty, each sub-task was analysed separately . When an error occurred on a given trial, it was assigned a value of $n + 1$, where n is the number of steps by which the patterns differed on that trial. Rightward errors (e.g. the patient judged a line longer on the right although it was longer on the left) were given a positive value, and leftward errors were given a negative value . By use of this rule, an identical pair of stimuli $(n=0)$ would yield a score of either $+1$ (if the "rightward" key was pressed) or -1 (if the "leftward" key was pressed) . The size of the error recorded thus increased with the difference between the stimuli . A total net error score was calculated in this way for each stimulus series for each subject. This scoring procedure was performed separately for the longer/larger instruction and for the shorter/smaller instruction, giving two independent error scores for each stimulus dimension tested.

The arithmetic mean of these two scores was then taken as a measure of the response bias (e .g . a patient showing net rightward responses on one particular stimulus series, with scores of $+5$ and $+4$ for the opposing instructions, would have an overall response bias of $+4.5$). For a measurement of the perceptual bias, the score attained on the shorter/smaller instruction was subtracted from that attained on the longer/bigger instruction, and the difference divided by 2. (In the above example, rightward error scores of $+5$ and $+4$ would be given an overall perceptual score of only $+0.5$. In contrast, a patient with only a perceptual bias would show rightward errors on the longer/bigger instruction, e.g. $+5$, but *leftward* errors on the shorter/smaller instruction, e.g. 4, thus yielding a perceptual score of +4.5) . Similar calculations were performed for stimulus comparisons between upper and lower visual space ("up" being signed as positive).

Table 2 shows the left/right matching data for the patient M.J. and for the control group. It is clear that M .J . showed a substantial constant error in the matching of both horizontal line length and figure area, whereas her performance with vertical lines did not differ from that of the control patients. The control patients showed almost perfect performance on all tasks . Both with horizontal lines and figure areas, M .J . tended to underestimate grossly the left-side stimulus relative to the right, such that her perceptual bias exceeded the mean of the control group by over 3 S.D.s in both cases. It is notable that she also had a rightward response bias with both stimulus materials.

As shown in Table 3, M.J. also tended to overestimate vertical and areal extents in the upper relative to the lower parts of the array ; her perceptual bias in the up/down direction exceeded the control mean by over $3 S.D.s$ in both cases. This bias would be consistent with the reports of bisection errors made by other neglect patients with vertical lines (e .g . Ref. [5]), which they tend to bisect too far upwards . Such bisection errors would not be predicted from

	Horizontal lines	Vertical lines	Nonsense figures
Perceptual bias			
M.L	-9.5	↔	$+9.0$
Controls	-1.29	0	0.77
(S.D.)	(1.90)	(3.54)	(2.89)
Response bias			
MJ.	$+8.5$	$+1.0$	$+7.0$
Controls	-0.13	$+0.31$	$+0.25$
(S.D.)	(1.49)	(1.55)	(2.40)

Table 2. Biases in perceptual matching of horizontal lines, vertical lines and nonsense figures between left and right sides of space . Data are given for a single neglect patient and for the control group . A positive score indicates a rightward preference . Further explanation is given in the text

M.J.'s up/down response biases, which if anything tended to be downward in the present task, though they were inconsistent.

Table 3. Biases in perceptual matching of horizontal lines, vertical lines and nonsense figures between upper and lower parts of space . A positive score indicates an upward preference

	Horizontal lines	Vertical lines	Nonsense figures
Perceptual bias			
M.J.	$+1.0$	$+8.0$	$+12.0$
Controls	$+0.08$	-0.13	1.16
(S.D.)	(0.99)	(2.02)	(3.24)
Response bias			
MJ.	-2.0	$+3.0$	-11.0
Controls	-0.08	-0.21	0
(S.D.)	(0.90)	(2.03)	(2.48)

DISCUSSION

The first question that this paper addresses is whether neglect patients perceive the midpoint of a horizontal line to be subjectively shifted to one side . Neither the generalized version of the space-compression hypothesis, nor the directional limb hypokinesia hypothesis, would predict this, since neither account predicts any nonlinear distortion of perception . The former account predicts only that the whole line should be subjectively shifted rightwards in space, along with a uniform shrinkage in its size . Yet here we have demonstrated in three patients with manifest hemispatial neglect, each showing large rightward bisection errors, that they consistently indicate the left end of a line as appearing closer to the objective midpoint . Indeed, even lines transected as far as 5 mm to the right of centre were predominantly judged in this way . Furthermore. since the patients responded manually, any directional hypokinesia [9] would predict a response bias opposite to this observed behaviour .

Therefore we conclude that in these hemispatial neglect patients there was indeed a tendency to perceive the left half of a line as shorter than the right half . This would in itself be sufficient to explain the large rightward errors seen in their line bisection behaviour . It is notable therefore that I.H., the patient showing the least dramatic bisection errors (and least neglect generally) also showed the smallest judgemental bias in the landmark task . Although one cannot make grand generalizations from three patients, it is notable that Marshall and Halligan's patient P.P., when shown centrally prebisected lines, indicated on 94% of trials they were "wrongly" bisected, and generally then "corrected" them toward the right [10] .

The second matter that this paper addresses is the frequently noted trend in neglect patients for line bisection errors to be greater in contralateral space than in ipsilateral visual space . Again the generalized spatial compression model could explain this, since it predicts that the subjective location of a line should be shifted rightwards to a greater extent within left hemispace than within right hemispace . This hypothesis alone, however, predicts no variation in the perceived appearance of a transected line placed in different parts of visual space. In contrast, MILNER $[11]$ suggested that patients with left hemineglect might perceive leftwardly-located spatial extents as shrunken relative to more rightward ones, and that the gradient of this distortion might be greater within left than in right hemispace . If this is correct, then the tendency to judge the left halves of lines as shorter than the right, which we report here in the landmark task, should become particularly pronounced in left hemispace . Although the numbers of observations are too few to assess statistically, it is nonetheless striking that we have observed precisely this trend in both of our patients in whom the responses did not hit a 100% ceiling.

Our landmark results are thus consistent with the hypothesis that neglect patients tend to judge the left half of a centrally bisected line as shorter, and that the gradient of distortion may be particularly pronounced in left hemispace . They therefore indicate that misdirected action as an account of line bisection is at best incomplete .

Finally, we have tested one neglect patient directly on her ability to match the relative size of pairs of computer-generated patterns . Again neither a uniform spatial compression nor a direction hypokinesia should in itself lead to any constant error in such tasks . Yet like GATNOTTI and TIACCI [3], we found gross errors in matching the sizes of stimuli presented to the left and right visual hemispace . However, these errors of relative underscaling in left hemispace were not indiscriminate; they were present in comparing horizontal extents, but not in comparing vertical extents . They were also present when comparing the sizes of abstract shapes differing in both their horizontal and vertical extents .

It could be argued that the task of matching vertical lines between left and right was simply geometrically easier than matching horizontal lines . However this interpretation is not supported by an analysis of the unsigned errors made by the control patients. Their mean error score for the left-right matching of vertical lines $(0.91; S.D. = 1.08)$ was identical to that for matching horizontal lines $(0.91, S.D. = 1.31)$.

While the generality of the present findings remains to be ascertained, we conclude that in at least some patients suffering from hemispatial neglect, there is a perceptual factor operating to render left-side stimuli subjectively smaller than rightwardly located ones . This phenomenon may be particularly pronounced in the perception of horizontal extent . We therefore argue that this distortion of size perception must play an important role in the causation of bisection errors in such patients . It should be emphasized . however, that distortions of size perception of the kind we have observed could coexist with a uniform spatial compression of the limited kind initially proposed by HALLIGAN and MARSHALL [6]. They did not explicitly generalize their hypothesis to apply to the sizes of objects . There could be two different changes in perceptual experience, one affecting the subjective spatial location of an item, the other its subjective size, which would not be mutually incompatible . The two factors could be present in combination, each to a different extent in different patients .

It is relevant to note that other investigators have recently argued for a perceptual factor in determining line bisection errors in neglect, to varying extents in different patients [1, 2] . For example, BISIACH et al. $[1]$ showed that some patients would move a manipulandum lcftwards from the spatial midline in order to set a transection pointer rightwards from the midpoint of a line that they were asked to bisect . Like the present data, this behaviour could not be explained by a leftward directional hypokinesia, or by a spatially misdirected aiming movement. Other patients, however, did give evidence for the operation of such a factor.

In a previous paper [12] we have shown that cueing can strongly influence both line bisection and landmark judgements in normal subjects, We argued that unilateral cueing directs selective attention unevenly to one or other end of the line, and therefore that the perception of relative size is subject to systematic distortion as a function of this selective attention within the visual field . Our present data can be interpreted as documenting an abnormal example of this attentionally-induced illusion . In neglect, the distribution of attentional resources may be assumed to be abnormally biased in a way that is only partially reversible under voluntary control. The result of this balance may be to cause, quite directly, a gross abnormality of size perception, which in turn is manifest in disordered bisection behaviour. Of course, such illusory size perception cannot explain instances in neglect patients of complete obliviousness to a whole object or object-part . Rather both of these observed phenomena must be assumed to be secondary to a gross attentional imbalance .

Acknowledgements-The authors are grateful to the Wellcome Trust for supporting this research, and to the Medical Research Council for support of S.V.F. on a research studentship. We also thank Michael Oram for his assistance in computer programming.

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