COMMENTARY

THE EYES HAVE IT: OCULOMOTOR EXPLORATION AND LINE BISECTION IN NEGLECT

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Abstract

In this issue of *Cortex*, Ishiai et al. (2006) report the eye movements of patients with left neglect during the bisection of lines of different lengths. This is the latest in a series of papers from Ishiai's group, which form an important corpus of data on the oculomotor behaviour of neglect patients during line bisection and related tasks. In this article, I argue that these data should critically constrain theoretical models of bisection errors in neglect, but that these constraints have been applied rarely in practice. First, I briefly introduce bisection behaviour in neglect and describe some of the models proposed to account for its character. I then consider the implications for these models of Ishiai and colleagues' observations. Finally, I outline a novel view of the bisection task that is more compatible with their observations.

Key words: unilateral spatial neglect, line bisection, cross-over, eye movements

Line Bisection and Neglect

The misbisected line may be less iconic than the half-empty clock face, but it has a far higher profile in the research literature on unilateral neglect. Considering the popularity and apparent simplicity of the task, however, the significance of line bisection impairment is still surprisingly little understood. Indeed, it is a matter of current debate whether pathological bisection errors should be considered as part of the neglect syndrome at all, given their relatively poor correspondence with other canonical measures, such as target cancellation omissions (Binder et al., 1992; Ferber and Karnath, 2001; Halligan and Marshall, 1992; McGlinchey-Berroth et al., 1996; Schubert and Spatt, 2001) or the omission of left-sided details on drawing tasks (Bisiach et al., 1976; Critchley, 1953; Schenkenberg et al., 1980).

Whether or not they are central to the syndrome, rightward errors of line bisection amongst neglect patients do require explanation. Clues as to their nature can be gleaned from the ways in which patients' responses change with variations in the stimulus lines. The bisection errors of neglect patients are sensitive both to line length, becoming more rightward for longer lines (Bisiach et al., 1983; Butter et al., 1988; Nichelli et al., 1989), and spatial position, becoming more rightward for lines presented at increasingly leftward locations (Heilman and Valenstein, 1979; Nichelli et al., 1989; Schenkenberg et al., 1980). The typical relationship between line length and bisection error in neglect is well-described by a positive linear function (Halligan and Marshall, 1988, 1989a; Marshall and Halligan, 1989, 1990; Riddoch and Humphreys, 1983). Extrapolation of this function predicts that, for some patients, the bisection error should reverse direction to become leftward for very short lines. This so-called "cross-over" effect (Halligan and Marshall, 1988) is now a familiar feature of neglect performance (Halligan and Marshall, 1989b; Harvey et al., 1995a; Marshall and Halligan, 1989; Tegnér and Levander, 1991a). Less familiar is the fact that an analogous cross-over effect can arise via the manipulation of spatial position, so that some patients make leftward errors for lines presented in right hemispace, though erring rightwards when lines of a similar length are presented at other locations (Harvey and Milner 1999; Ishiai et al., 1989; Mennemeier et al., 2001).

Perceptual and Motor Accounts

A simple way to explain rightward bisection errors in neglect is to suppose that the patient fails to see some leftward portion of the line but correctly bisects the subtotal portion that they do see (Bisiach et al., 1983). This hypothesis has intuitive appeal and would predict a linear fit between bisection error and line length. However, Halligan and Marshall (1989a) established that the range of values of the slope of the line length effect amongst neglect patients far exceeds that predicted by a simple perceptual "amputation" model. Furthermore, many patients persist in making rightward errors after their attention has been drawn to the left endpoint of the line (e.g., Heilman and Valenstein, 1979; Harvey et al., 1995b; Ishiai et al., 1995; Nichelli et al., 1989;

Riddoch and Humphreys, 1983). These findings imply that bisection errors in neglect cannot be explained by perceptual amputation alone. Instead, explanations based on the broad concept of perceptual "distortion" have risen to prominence. These propose that leftward portions of the line, although seen in their entirety, are perceived as laterally compressed relative to rightward extents (e.g., Bisiach et al., 1996; Halligan and Marshall, 1991; Milner, 1987).

Traditionally, perceptual accounts of rightward bisection errors have been contrasted with motoric accounts, according to which patients program movements too far towards the ipsilesional side (Heilman and Valenstein, 1979). Several techniques have been used to demonstrate a contribution of motor biases to the clinical symptoms of neglect (e.g., Bisiach et al., 1990; Coslett et al., 1990; Tegnér and Levander, 1991b). Many of these techniques have been criticised (Husain et al., 2000; Mattingley and Driver, 1997), however, and it has emerged that there is little or no consistency between the results that they produce (Harvey et al., 2002). Whilst the influence of motoric accounts has receded, the resemblance of the line length effect to normal psychophysical relationships has spurred the development of more quantitative, perceptually-rooted models of neglect bisection behaviour.

Psychophysical Models

A psychophysical approach was adopted by Chatterjee et al. (1994a, 1994b), who used power functions to map the relationship between objective and subjective line length (calculated as twice the distance between the transection mark and the right endpoint). Left neglect patients had a diminished exponent relative to controls, and were characterised as having a dampened appreciation of changes in line length, presumably due to an underestimation of the left side. In a subsequent revision of the model, Chatterjee (2002) fitted power functions to the relationship between left and right created portions across a range of line lengths, quantifying the putative perceptual distortion more directly. In explaining the cross-over effect, however, this model faces the same difficulty as does any account based on perceptual distortion. If rightward errors are due to relative underestimation of the left, then leftward errors must be explicable in terms of its relative *overestimation*. Chatterjee (1995) suggested that, in addition to underestimating leftward extents, neglect patients tend to confabulate extension of lines towards this side. For long lines, the confabulated extent would typically have no influence, but for short lines it could extend beyond the left hand end of the objective line and precipitate leftward errors.

A very different psychophysical analysis was offered by Marshall and Halligan (1989). Their account begins with the premise that the bisection task requires the subject to transect a line such that the two created lengths are subjectively equal. This judgement is subject to Weber's law, which in this context holds that the "just noticeable difference" between the two line segments is a constant proportion (Weber fraction) of the stimulus length. Marshall and Halligan (1989) argued that the size of a subject's Weber fraction will be reflected in the range of transections produced for a given line; this is typically higher in neglect patients than in normal subjects, suggesting an inflated Weber fraction for horizontal extents. Secondly, Marshall and Halligan (1989) propose that bisection responses are made by moving attention from one end of the line towards the "zone of indifference", within which transections are not subjectively asymmetrical. If the transection is placed (roughly) at the point of entry into this zone, then a left-to-right scan will yield a leftward error, and a right-to-left scan will yield a rightward error. Left neglect patients have a strong tendency to orient initially rightwards (e.g., Kinsbourne, 1993), increasing the probability that scanning will commence from this side and that errors will be rightward.

The "scantrack" model is intriguing, particularly because it does not appeal to any asymmetry of perception to explain the asymmetry of bisection. The primary impairment attributed to neglect patients is that they are imprecise in judging the midpoint, which tends to dictate that their errors are large; a co-existing tendency to orient initially rightwards accounts for the fact that these large errors are rightward. In order to explain the cross-over effect, Marshall and Halligan (1989) proposed that, since short lines may be viewed in a single fixation, neglect patients might revert to a more normal pattern of left-to-right attentional scanning. We might additionally suppose that the presentation of stimulus lines within right hemispace will increase the likelihood of a left-to-right scan, which could potentially account for cross-over bisections in right hemispace (Harvey and Milner 1999; Ishiai et al., 1989; Mennemeier et al., 2001).

Oculomotor Exploration and Line Bisection in Neglect

In this issue of *Cortex*, Ishiai et al. (2006) report the eye movements of four patients with left neglect asked to bisect lines of three different lengths. The longest lines (200 mm) are within the range typically used for the diagnosis of neglect, whilst the shortest are within the "very short" range (25 mm) expected to elicit cross-over bisections in a proportion of patients. Assuming that the patients' eye movements are a valid indicator of the direction of their spatial attention, this should provide a simple evaluation of Marshall and Halligan's (1989) scantrack model of bisection behaviour. Specifically, it should test the idea that bisection errors reflect the direction of attentional approach to the subjective midpoint, and that cross-over bisections are associated with a reversal of the patients' normal right-to-left scanning patterns. Remarkably, this represents the first explicit test of the scantrack model since it was proposed more than 15 years ago.

The model, in its original form, is clearly falsified by Ishiai et al.'s (2006, this issue) new data. There was no predictive relationship between direction of final scan and direction of bisection error, nor was there any evidence that right-to-left overt scans predominate amongst neglect patients making bisection responses. In fact, left-to-right approaches to the subjective midpoint predominated in three patients, and the fourth showed an even mix of directionally-opposed scans. These results are qualified by the fact that the patients failed to explore to the left end of the line in the vast majority of trials for the two longer line lengths. Three of the patients had left homonymous hemianopia, so could not have seen the whole line. The other patient had left extinction and, it is argued, would probably have had his awareness similarly restricted to the portion of the line between its right endpoint and his leftmost fixation. The patients' bisection responses can be evaluated not just with respect to the entire line, but also with respect to this "attended" segment. The three patients that made mostly rightward approaches to the subjective midpoint all bisected the attended segment significantly leftwards. The fourth patient, who showed an even mix of leftward and rightward scans, did not bisect attended segments with a significant mean directional error. Overall, the data suggest that the direction of approach *might* influence the deviation of the subjective midpoint *on the attended segment of the line*. Some version of the scantrack model might thus be applicable, though it would need to be a radical modification of the original model.

Ishiai et al.'s (2006, this issue) data similarly have fundamental implications for other models of bisection behaviour in neglect. The inaccurate placement of responses on the attended segment provides a straightforward refutation of the amputation account (Bisiach et al., 1983), according to which patients should bisect the viewed portion correctly. Likewise, the existence of left neglect patients who make grossly leftward rather than rightward errors on the attended segment is problematic for perceptual distortion accounts. It should be noted that this critical finding is not novel but was reported in the very first study of neglect patients' eye movements during line bisection (Ishiai et al., 1989), and has been replicated many times since (Ishiai et al., 1992, 1995, 1996, 2001; Ishiai, 2002). Indeed, over 16 years, Ishiai and colleagues have amassed a weighty corpus of data that establishes beyond doubt the basic character of neglect patients' exploratory eye movements during bisection tasks, and their relationship to bisection responses.

When presented with a horizontal line, neglect patients may launch a few eye-movements rightwards from their initial fixation, but will rarely or never look leftwards before bisecting, typically with a rightward error (Ishiai et al., 1989, 1992, 1995, 2001; Kim et al., 1997). If the bisection response is mapped onto the attended segment, it usually lies well towards the left of this segment, and often coincides with the leftmost fixation (Ishiai et al., 1989, 1992, 1995, 2001). This is the dominant pattern, but the exceptions to the rule are also highly informative. Thus, neglect patients occasionally make leftward searches spontaneously (Ishiai et al., 1996; Ishiai, 2002), or when the experimenter encourages (Barton et al., 1998) or compels them to do so (Ishiai et al., 1992, 1995, 2001). Under such circumstances, the patient may still make a rightward bisection error, but now by responding *rightwards* on the attended segment. No consistent deviation of responses can be deduced with respect to the attended segment, and the bisection error is remarkably little affected by variations in the leftward extent of exploration (Ishiai et al., 1995, 1996, 2001; Misonou et al., 2004).

These facts are perplexing when viewed within a traditional framework. However, like the relationship of bisection error to line length, they are reliable empirical findings. We may thus ask why they have seemingly had little influence on the development of contemporary models of neglect bisection behaviour, whilst the relationship between line length and bisection error has been central to the enterprise. A possible explanation is that these data undermine two core assumptions on which such models are founded (including several computational models not covered here). The first is that line bisection tests the ability of neglect patients to compare left and right extents, and that their response reflects the outcome of this comparison process. The second is that a lawful influence of line length shows that the patients must, at some level, process the entire line, so that normal psychophysical principles can be applied. In order to accommodate Ishiai and colleagues' observations, it may be necessary to suspend both of these assumptions.

A Novel View of Neglect Bisection Behaviour

An additional manipulation that Ishiai and colleagues have employed is to show patients their own bisection responses, whilst forcing them to fixate the left endpoint of the line. Patients can usually recognise the inadequacy of their bisections under these conditions (Ishiai et al., 1989), even when viewing *cued* bisection responses, made after being similarly forced to fixate leftwards (Ishiai et al., 1995, 1996). Likewise, when shown pre-transected lines, they can detect deviations far smaller than their errors of bisection for comparable lines (Ishiai et al., 1998; Marshall and Halligan, 1995). This difference is not due to motoric biases affecting bisection responses, because the same pattern holds for a "line bisection by fixation" task that has no manual component (Ishiai et al., 1998). Moreover, neglect patients may perform well when required to extend a line leftwards to double its length, suggesting that motor factors do not limit their performance. They also execute this line extension task with far greater symmetry than their bisection performance would predict (Ishiai et al., 1994a, 1994b).

These results suggest that neglect patients understand the concept of length comparison and that the perceptual asymmetries they may have for such comparisons do not account quantitatively for their bisection errors. Harvey et al. (1995a) have also observed discrepancies between bisection and comparison tasks, reporting that most neglect patients identified the left half of a pre-bisected line as shorter than the right, even for short lengths that elicited *leftward* errors of bisection. Such findings, in tandem with the oculomotor patterns described earlier, have led Ishiai et al. (1998) to the counter-intuitive conclusion that "*line bisection is not a task that examines the ability of patients with neglect to compare the right and left extents of a line*" (p. 239). They have hypothesised that severe neglect patients, when presented with an unmarked line, may respond exclusively with respect to the right endpoint, regardless of how far leftwards they have explored (see also Kinsbourne, 1993). Although some suggestive data have been produced to this effect (Koyama et al., 1997; Ishiai et al., 2000), the hypothesis has not been tested, since the locations of the left and right endpoints of the line have not been manipulated independently. However, we have recently performed a series of bisection studies that incorporate this manipulation, and have obtained strong evidence to support the proposal.

Figures 1a-1c display the mean responses made by a patient with severe left neglect and homonymous hemianopia to each of a series of lines presented in three bisection experiments (McIntosh et al., 2005). Figures 1a and 1b show clearly that the location of responding, relative to the body midline, is unaffected by changes at the left end of the line, whilst slavishly (though incompletely) tracking the location of the right endpoint. This yields the classical effects of line length and spatial position, with bisection errors becoming more rightward for longer lines and for lines at more leftward locations. This is shown vividly in Figure 1c, in which traditional manipulations of line length and spatial position are illustrated. The pronounced cross-over effect for the shortest line should also be noted (Figures 1b and 1c). The influence of each endpoint can be quantified as an "endpoint weighting", which is the mean proportion of the change in the endpoint location that is mirrored by change in the location of the response (Figure 1d). The pattern of weightings is consistent across experiments, with the left endpoint having effectively no influence, and the right endpoint having far too much.

The patient illustrated here is selected from a series of 30 patients with varying degrees of neglect. His behaviour is representative of many severe patients, with and without hemianopia, in that the left endpoint had no significant influence upon the location of the response. In a greater number of cases, the left endpoint *did* have an influence, but this was invariably smaller than that of the right endpoint, even in patients who did not bisect abnormally rightwards on average. These findings are discussed fully in McIntosh et al. (2005). For present purposes, however, there are three main implications: first, that it is possible to model neglect bisection behaviour accurately without assuming that the response represents the outcome of a comparison between left and right extents, or that the entire line is seen; second, that cross-over effects do not require any special explanation but, like rightward errors, may arise when the location of the left endpoint is not represented in awareness; third, that apparently accurate bisections are also possible under these circumstances, so that the absence of abnormally rightward errors cannot be taken to imply absence of neglect on this task.

Conclusion and Completion

The considerable contribution that Ishiai and colleagues have made over the past 16 years to elucidating the mechanisms of line bisection in patients with neglect may have been under-appreciated due to the absence of an adequate descriptive framework within which to understand their data. It is hoped that the endpoint weightings model sketched briefly here, in which the left and right endpoints of the line are considered as having independent influences upon bisection responses, may offer such a framework. In its simple form, the model is merely a quantitative re-description of neglect patients' behaviour; it does not explain the behaviour. However, it should at least focus the search for an explanation somewhere other than on the directional error of bisection. The primary features to be explained for each patient are the values of their left and right endpoint weightings. Some preliminary hypotheses concerning the significance of these weightings have been

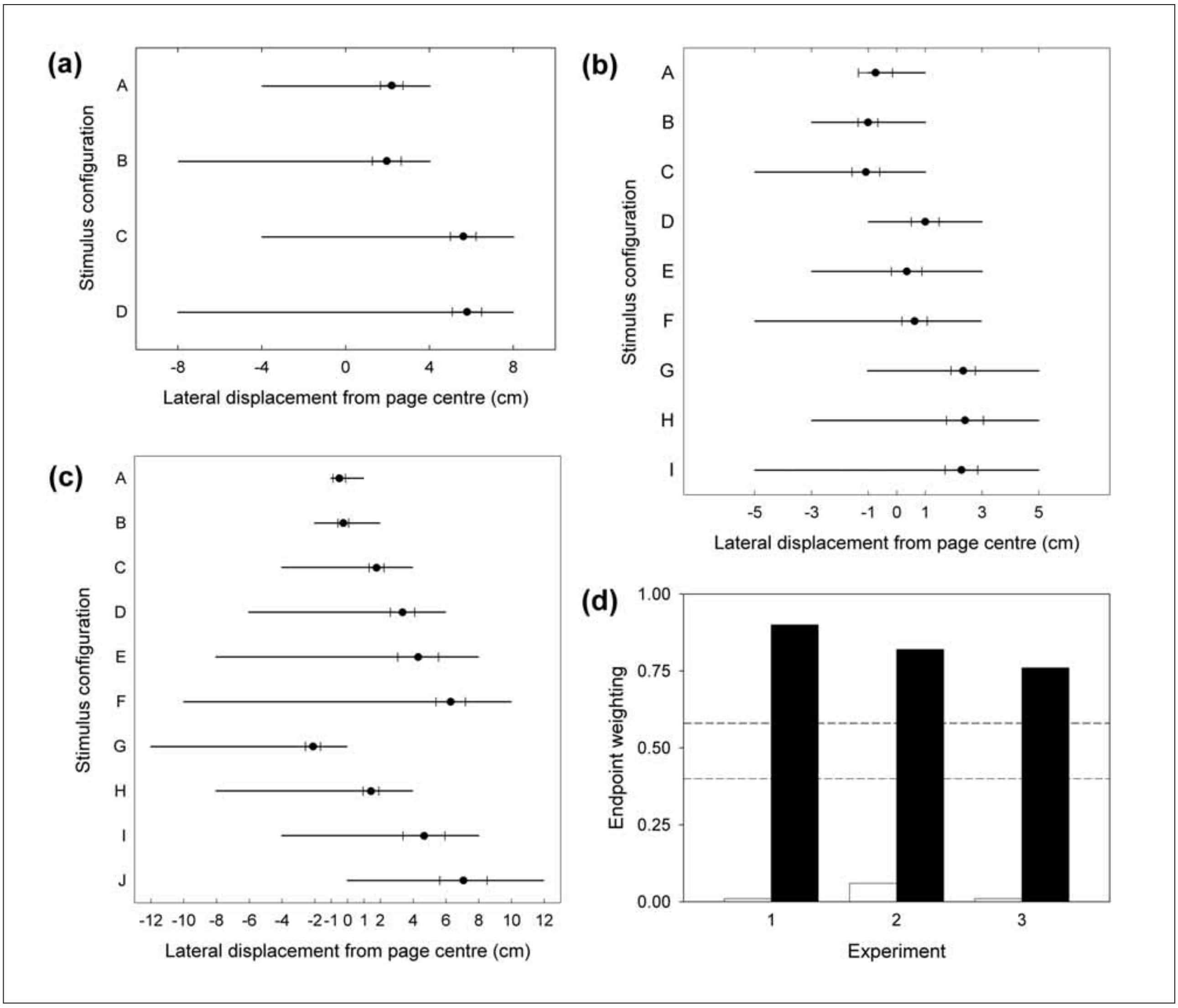

Fig 1 – *Data from three bisection experiments for a patient with left neglect. This patient (VN6) is taken from a case series of 30, reported by McIntosh et al. (2005). In each experiment, each line was presented individually on a sheet of A4 paper, which was centred at the body midline (zero lateral coordinate). Each stimulus configuration was presented eight times in a pseudo-random sequence. In Experiments 1 and 2, the left and right endpoint locations were manipulated independently, whilst Experiment 3 encompassed traditional manipulations of line length and spatial position. (a) Mean bisection responses (± SD) for Experiment 1. The left endpoint had no significant influence, but bisection responses were strongly related to right endpoint location. (b) Mean bisection responses (± SD) for Experiment 2. The same pattern was maintained across a range of shorter lines. Note the pronounced cross-over effect for the shortest line (line A). (c) Mean bisection responses (± SD) for Experiment 3. Classical effects of line length and spatial position were obtained, including a cross-over effect for the shortest line (line A). These effects emerged naturally from the same pattern of behaviour observed in Experiments 1 and 2. Note that lines C, H, I and E match lines A, B, C and D in Experiment 1 (panel a), as does the pattern of responses made to them. (d) Endpoint weightings for each experiment, representing the proportion of the change in endpoint location that was reflected in the response. The light bars represent the left endpoint weightings, and the dark bars represent the right endpoint weightings. In each experiment, the left endpoint weighting was close to zero, whilst the right endpoint weighting was greater than .75. The dashed lines represent the minimum and maximum endpoint weighting observed for either endpoint amongst a group of 30 healthy elderly subjects performing Experiment 1.*

proposed by McIntosh et al. (2005).

Finally, the fact that patients with neglect may respond with little or no regard to the left endpoint of the line inevitably raises the question of what they experience when doing so. It may be possible for us to determine that a patient's response does not result from the comparison of left and right extents, but is this how it appears to the patient? Kinsbourne (1993) suggested that neglect patients transect optimistically at some distance from the right endpoint, being simply unable to sustain a concurrent awareness of the left. By contrast, Ishiai et al. (1989, 1992) propose that the decision to fixate at a certain point on the line, however it may be determined, is accompanied by the subjective impression of the line extending equally into the inattentive or blind field. It is not clear that this is a necessary inference, since there are reasons to suspect that other apparent instances of pathological visual completion may reflect unawareness of the absence of contralesional information, rather than an active process of filling-in (Walker and Mattingley, 1997). On the other hand, if the present article shows anything, it is surely that it would be unwise to dismiss Ishiai and colleagues' speculations prematurely.

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References

BARTON JJS, BEHRMANN M and BLACK S. Ocular search during line bisection. The effects of hemi-neglect and hemianopia. *Brain, 121:* 1117-1131, 1998.

BINDER J, MARSHALL R, LAZAR, R, BENJAMIN J and MOHR JP. Distinct syndromes of hemineglect. *Archives of Neurology, 49:* 1187-1194, 1992.

BISIACH E, BULGARELLI C, STERZI R and VALLAR G. Line bisection and cognitive plasticity of unilateral neglect of space. *Brain and Cognition, 2:* 32-38, 1983.

BISIACH E, CAPITANI E, COLOMBO A and SPINNLER H. Halving a horizontal segment: A study on hemisphere-damaged patients with cerebral focal lesions. *Archives Suisses de Neurologie, Neurochirurgie et de Psychiatrie, 118:* 199-206, 1976.

BISIACH E, GEMINIANI G, BERTI A and RUSCONI ML. Perceptual and premotor factors of unilateral neglect. *Neurology, 40:* 1278-1281, 1990.

BISIACH E, PIZZAMIGLIO L, NICO D and ANTONUCCI G. Beyond unilateral neglect. *Brain, 119:* 851-857, 1996.

BUTTER CM, MARK VW and HEILMAN KM. An experimental analysis of factors underlying neglect in line bisection. *Journal of Neurology, Neurosurgery, and Psychiatry, 51:* 1581-1583, 1988.

CHATTERJEE A. Cross-over, completion and confabulation in unilateral spatial neglect. *Brain, 118:* 455-465, 1995.

CHATTERJEE A. Spatial anisometry and representational release in neglect. In Karnath H-O, Milner AD and Vallar G (Eds), *The Cognitive and Neural Bases of Spatial Neglect*. New York: Oxford University Press, 2002.

CHATTERJEE A, DAJANI BM and GAGE RJ. Psychophysical constraints on behavior in unilateral spatial neglect. *Neuropsychiatry, Neuropsychology, and Behavioral Neurology, 7:* 267-274, 1994a.

CHATTERJEE A, MENNEMEIER M and HEILMAN KM. The psychophysical power law and unilateral spatial neglect. *Brain and Cognition, 25:* 92-107, 1994b.

COSLETT HB, BOWERS D, FITZPATRICK E, HAWS B and HEILMAN KM. Directional hypokinesia and hemispatial inattention in neglect. *Brain, 113:* 475-486, 1990.

CRITCHLEY M. *The Parietal Lobes*. London: Arnold, 1953.

FERBER S and KARNATH H-O. How to assess spatial neglect – Line bisection or cancellation tasks? *Journal of Clinical and Experimental Neuropsychology, 23:* 599-607, 2001.

HALLIGAN PW and MARSHALL JC. How long is a piece of string – A study of line bisection in a case of visual neglect. *Cortex, 24:* 321-328, 1988.

HALLIGAN PW and MARSHALL JC. Line bisection in visuo-spatial neglect – Disproof of a conjecture. *Cortex, 25:* 517-521, 1989a.

HALLIGAN PW and MARSHALL JC. Perceptual cueing and perceptuo-motor compatibility in visuo-spatial neglect – A single case-study. *Cognitive Neuropsychology, 6:* 423-435, 1989b.

HALLIGAN PW and MARSHALL JC. Spatial compression in visual neglect: A case study. *Cortex, 27:* 623-629, 1991.

HALLIGAN PW and MARSHALL JC. Left visuospatial neglect – A meaningless entity. *Cortex, 28:* 525-535, 1992.

HARVEY M, KRAMER-MCCAFFERY T, DOW L, MURPHY PJS and GILCHRIST ID. Categorisation of "perceptual" and "premotor" neglect patients across different tasks: Is there strong evidence for a dichotomy? *Neuropsychologia, 40:* 1387-1395, 2002.

HARVEY M and MILNER AD. Residual perceptual distortion in "recovered" hemispatial neglect. *Neuropsychologia, 37:* 745-750, 1999.

HARVEY M, MILNER AD and ROBERTS RC. Differential effects of line length on bisection judgements in hemispatial neglect. *Cortex, 31:* 711-722, 1995a.

HARVEY M, MILNER AD and ROBERTS RC. An investigation of hemispatial neglect using the landmark task. *Brain and Cognition, 27:* 59-78, 1995b.

HEILMAN KM and VALENSTEIN E. Mechanisms underlying hemispatial neglect. *Annals of Neurology, 5:* 166-170, 1979.

HUSAIN M, MATTINGLEY JB, RORDEN C, KENNARD C and DRIVER J. Distinguishing sensory and motor biases in parietal and frontal neglect. *Brain, 123:* 1643-1659, 2000.

ISHIAI S. Perceptual and motor interaction in unilateral spatial neglect. In Karnath H-O, Milner AD and Vallar G (Eds), *The Cognitive and Neural Bases of Spatial Neglect*. New York: Oxford University Press, 2002.

ISHIAI S, FURUKAWA T and TSUKAGOSHI H. Visuospatial processes of line bisection and the mechanisms underlying unilateral spatial neglect. *Brain, 112:* 1485-1502, 1989.

ISHIAI S, KOYAMA Y and SEKI K. What is line bisection in unilateral spatial neglect? Analysis of perceptual and motor aspects in line bisection tasks. *Brain and Cognition, 36:* 239-252, 1998.

ISHIAI S, KOYAMA Y and SEKI K. Significance of paradoxical leftward error of line bisection in left unilateral spatial neglect. *Brain and Cognition, 45:* 238-248, 2001.

ISHIAI S, KOYAMA Y, SEKI K, HAYASHI K and IZUMI Y. Approaches to subjective midpoint of horizontal lines in unilateral spatial neglect. *Cortex, 42:* 2006.

ISHIAI S, KOYAMA Y, SEKI K and IZAWA M. Line versus representational bisections in unilateral spatial neglect. *Journal of Neurology Neurosurgery and Psychiatry, 69:* 745-750, 2000.

ISHIAI S, SEKI K, KOYAMA Y and GONO S. Ineffective leftward search in line bisection and mechanisms of left unilateral spatial neglect. *Journal of Neurology, 243:* 381-387, 1996.

ISHIAI S, SEKI K, KOYAMA Y and OKIYAMA R. Effects of cueing on visuospatial processing in unilateral spatial neglect. *Journal of Neurology, 242:* 367-373, 1995.

ISHIAI S, SUGISHITA M, MITANI K and ISHIZAWA M. Leftward search in left unilateral spatial neglect. *Journal of Neurology Neurosurgery, and Psychiatry, 55:* 40-44, 1992.

ISHIAI S, SUGISHITA M, WATABIKI S, NAKAYAMA T, KOTERA M and GONO S. Improvement of unilateral spatial neglect in a line extension task. *Neurology, 44:* 292-298, 1994a.

ISHIAI S, WATABIKI S, LEE E, KANOUCHI T and ODAJIMA N. Preserved leftward movement in left unilateral spatial neglect due to frontal lesions. *Journal of Neurology, Neurosurgery, and Psychiatry, 57:* 1085-1090, 1994b.

KIM MH, ANDERSON JM and HEILMAN KM. Search patterns using the line bisection test for neglect. *Neurology, 49:* 936-940, 1997.

KINSBOURNE M. Orientational bias model of unilateral neglect: Evidence from attentional gradients within hemispace. In Robertson IH and Marshall JC (Eds), *Unilateral Neglect: Clinical and Experimental Studies*. Hove: Lawrence Erlbaum Associates, 1993.

KOYAMA Y, ISHIAI S, SEKI K and NAKAYAMA T. Distinct processes in line bisection according to severity of left unilateral spatial neglect. *Brain and Cognition, 35:* 271-281, 1997.

MARSHALL JC and HALLIGAN PW. When right goes left – An investigation of line bisection in a case of visual neglect. *Cortex, 25:* 503-515, 1989.

MARSHALL JC and HALLIGAN PW. Line bisection in a case of visual neglect – Psychophysical studies with implications for theory. *Cognitive Neuropsychology, 7:* 107-130, 1990.

MARSHALL JC and HALLIGAN PW. Within- and between-task dissociations in visuo-spatial neglect: A case study. *Cortex, 31:* 367-376, 1995.

MATTINGLEY JB and DRIVER J. Distinguishing sensory and motor deficits after parietal damage: An evaluation of response selection biases in unilateral neglect. In Thier P and Karnath H-O (Eds), *Parietal Lobe Contributions to Orientation in 3D Space*. Heidelberg: Springer, 1997.

MCGLINCHEY-BERROTH R, BULLIS DP, MILBERG WP, VERFAELLIE M, ALEXANDER M and D'ESPOSITO M. Assessment of neglect reveals dissociable behavioural but not neuroanatomical subtypes. *Journal of the International Neuropsychological Society, 2:* 441-451, 1996.

MCINTOSH RD, SCHINDLER I, BIRCHALL A and MILNER AD. Weights and measures: A new look at bisection behaviour in neglect. *Cognitive Brain Research, 25:* 833-850, 2005.

MENNEMEIER M, RAPCSAK SZ, PIERCE C and VEZEY E. Crossover by line length and spatial location. *Brain and Cognition, 47:* 412-422, 2001.

MILNER AD. Animal models for the syndrome of spatial neglect. In Jeannerod M (Ed), *Neurophysiological and Neuropsychological Aspects of Spatial Neglect*. Amsterdam: Elsevier, 1987.

MISONOU K, ISHIAI S, SEKI K, KOYAMA Y and NAKANO N. How do patients with neglect see a horizontal line? Analysis of performances in coloured line bisection task. *Journal of Neurology, 251:* 696-703, 2004.

NICHELLI P, RINALDI M and CUBELLI R. Selective spatial attention and length representation in normal subjects and in patients with unilateral spatial neglect. *Brain and Cognition, 9:* 57-70, 1989.

RIDDOCH MJ and HUMPHREYS GW. The effect of cueing on unilateral neglect. *Neuropsychologia, 21:* 589-599, 1983.

Schenkenberg T, Bradford DC and Ajax ET. Line bisection and unilateral visual neglect in patients with neurologic impairment. *Neurology, 30:* 509-517, 1980.

Schubert F and Spatt J. Double dissociations between neglect tests: Possible relation to lesion site. *European Neurology, 45:* 160-164, 2001.

Tegnér R and Levander M. The influence of stimulus properties on visual neglect. *Journal of Neurology, Neurosurgery, and Psychiatry, 54:* 882-887, 1991a.

Tegnér R and Levander M. Through a looking-glass – A new technique to demonstrate directional hypokinesia in unilateral neglect. *Brain, 114:* 1943-1951, 1991b.

Walker R and Mattingley JB. Ghosts in the machine? Pathological visual completion phenomena in the damaged brain. *Neurocase, 3:* 313-335, 1997.

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