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The end of the line: antagonistic attentional weightings in unilateral neglect

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Abstract

The line bisection task is widely used in the study of neglect. Some years ago, McIntosh, Schindler, Birchall, & Milner (2005) proposed a radical reframing of this ubiquitous task. Rather than using the traditional measure of directional bisection error, they quantified the sensitivities of the response to the changing locations of the left and right endpoints of the line, expressing these as 'endpoint weightings'. A novel prediction generated from their analysis was that manipulations increasing attention to the left end of the line should cause an increase in the left endpoint weighting and a corresponding reduction in the right endpoint weighting. The present study fulfilled this prediction, using a forced-report cueing method in a group of 12 patients with left neglect. The data confirm an antagonistic relationship between endpoint weightings, consistent with the idea that they represent the sharing of a finite resource. It is argued that the endpoint weightings model of line bisection offers a sensitive and uniquely useful framework for studying competitive lateral biases of attention in neglect, and may also provide insight into non-lateralised attentional impairments.

Introduction

Patients with left visual neglect typically make rightward errors when asked to bisect a horizontal line. On the assumption that the patients transect at their subjective midpoint, these errors may be taken to imply an asymmetrical perception of horizontal extent. This simple diagnostic task is readily adapted for experimental purposes. One illuminating manipulation is the cueing technique, in which symbols are placed at one or both ends of the line to be bisected (Heilman & Valenstein, 1979). Riddoch & Humphreys (1983) found that left-end cues had little influence on patients with left neglect, unless they were required to report them, in which case their rightward errors were markedly reduced. This led the authors to their highly influential conclusion that neglect results from a failure of *automatic* orienting of attention, with the capacity for conscious orienting relatively preserved. Lack of automatic attention to the left end of the line would entail that a leftward portion is perceived as truncated or compressed, leading to rightward errors: forced report of left cues would rebalance attentional distribution across the line.

Riddoch & Humphreys' (1983) theoretical inference was sound; but on the other hand there are persistent concerns around the assumption that directional bisection error actually indexes attentional bias in neglect. For example, the rightward errors made by neglect patients can paradoxically cross-over to become leftward when very short lines are presented (Halligan & Marshall, 1988; Marshall & Halligan, 1989; Tegnér & Levander, 1991), or when lines are presented to the right side of space (Mennemeier, Rapcsak, Pierce, & Vezey, 2001), which seems to suggest that left neglect is transformed into right neglect under special conditions. Even for normal length lines in mid space, a proportion of patients with left neglect on other diagnostic tests will bisect normally, or make anomalous leftward errors (Ferber & Karnath, 2001). Conversely, some patients with rightward bisection errors may perform well on other diagnostic tests of neglect, suggesting a double dissociation of underlying functions (Bisiach, Capitani, Colombo, & Spinnler, 1976; Halligan & Marshall, 1992). The correlation between bisection error and other core measures of neglect is consequently lower than would be expected for measures of a common attentional bias (Binder, Marshall, Lazar, Benjamin, & Mohr, 1992). Given these inconsistencies, it has recently been suggested that line bisection is simply not a valid task to diagnose neglect (Sperber & Karnath, 2016).

However, the main problem may not be in using the bisection task itself, but in making bisection error the measure of bias on the task. To express the response as a bisection error is to assume that it marks the subjective midpoint, but there are compelling reasons to doubt that patients with severe neglect really perceive a subjective midpoint at all (Kinsbourne, 1993). Rather, they may be limited in their ability to attend to both ends of the line simultaneously, in extreme cases framing their response solely with respect to the right endpoint (Koyama et al., 1997; McIntosh, 2006; McIntosh et al., 2005). A patient with no knowledge of the left endpoint location might make rightward, leftward, or accurate bisections, depending upon how far from the right endpoint they respond. Any of these outcomes could be due to neglect of the left, but only the occurrence of rightward errors would be consistent with this diagnosis under the traditional task analysis.

Some years ago, we proposed an alternative analysis that does not assume that the bisection response is a meaningful midpoint estimate (McIntosh et al., 2005). Indeed, it makes no assumptions at all about the patient's intentions, or about their experience during the task. Instead of being coded as an error relative to the objective midpoint, in this new approach the response is coded simply as a lateral spatial coordinate in the workspace. The left and right endpoints of the line are similarly coded as lateral coordinates. By varying the two endpoint locations independently across bisection stimuli, we can separately compute the 'weighting' that each endpoint has in determining the response. Numerically, the endpoint weighting is the slope of the linear function relating changes in response position to changes in one endpoint location when the other is held constant; perfect performance would yield symmetrical weightings of 0.5. In 30 patients with left neglect, we found that the left endpoint weighting was consistently lower than this ideal, and lower than the right endpoint weighting. Moreover, left and right endpoint weightings were inversely related across patients, suggesting an antagonistic relationship between the two, with the left endpoint at a competitive disadvantage for the control of the behaviour (McIntosh et al., 2005).

To capture this competition, we proposed a simple composite measure, *endpoint weightings bias* (EWB): the subtraction of the left endpoint weighting from the right endpoint weighting. Twenty-two patients (from 30) exceeded the normal cut-off for left neglect on EWB, whereas only a subset of 15 of these patients qualified for neglect by virtue of an abnormally rightward bisection error. This suggested that EWB is a highly sensitive measure of neglect, perhaps indexing the difference in attention allocated to the two endpoints. As a corollary of this proposal, taking the sum rather than the difference of the two weighting scores might index the patient's total attentional resource for the task. This *endpoints weightings sum*

(EWS) was typically lower than one amongst our neglect patients, yet was uncorrelated with EWB. This would be compatible with evidence that non-lateralised reductions in attention and arousal co-occur with neglect, but are functionally separable from its lateralised symptoms (Husain, 2005; Robertson, 1993).

Calculation of endpoint weightings, and the composite measures derived from them, requires a specific format of the line bisection task, in which left and right endpoints are manipulated independently. Only one study has so far done this, so evidence on the significance and utility of the endpoint weightings is lacking. The present study was designed to test one of the main predictions generated by that original paper (McIntosh et al., 2005, section 4.3). Specifically, if EWB represents the outcome of an attentional competition, then the two endpoint weightings should not only be inversely inter-related across patients, they should also be inversely related *within* patients, such that manipulations that selectively increase the weighting for one endpoint will entail a proportional decrease in weighting for the other. If the competition is tightly antagonistic, then such manipulations should induce marked changes in EWB (the difference between the weightings) but have little or no effect upon EWS (the sum of the weightings). The present study tests these predictions, by combining the forced-report cueing technique of Riddoch & Humphreys (1983) with the endpoint weightings format of line bisection devised by McIntosh and colleagues (2005).

Methods

VN patient	Age /sex	Lesion site	Post-stroke	VFD	Lines L/R	Stars L/R	Copy (sym/it)	Draw (0-3)	Bisect (mm)
VN01	68/M	na	17	-	0/0	4/4	5/5	0	**8.9**
VN02	59/M	FTPS	257	IQ	**100/28**	**100/48**	**1/1**	**1**	**34.0**
VN03	67/M	FTPS	32	-	0/0	**56/7**	**2/3**	**1**	**11.9**
VN04	59/M	TFS	43	-	6/0	**100/4**	5/5	**2**	-2.1
VN05	87/M	S	45	-	**39/0**	**59/30**	**4/4**	**1**	-0.4
VN06	74/M	PTS	127	-	0/0	**63/0**	**4/5**	0	**19.4**
VN07	78/M	FP	111	-	0/0	7/11	**4/5**	0	6.7
VN08	70/M	FP	336	-	6/0	19/19	**1/2**	**1**	**21.3**
VN09	72/F	TP	40	-	**33/0**	**100/44**	**1/2**	**3**	**19.9**
VN10	66/F	FTPS	63	-	6/0	**63/11**	**1/2**	0	**48.4**
VN11	65/M	TPS	443	H	**11/0**	**85/59**	**1/2**	**1**	**30.2**
VN12	65/M	FP	46	H	**100/0**	**100/59**	**1/2**	**3**	**48.4**

Table 1. *Clinical details of visual neglect (VN) patients. Lesion site determined from acute clinical CT scan: F, frontal; T, temporal; P, parietal; S, subcortical; na, not available. Time post-stroke is given in days. VFD, visual field defect to confrontation (H = hemianopia; IQ = inferior quadratanopia). Lines (L/R), % omissions in each half of line crossing sheet. Stars (L/R), % omissions in each half of star cancellation sheet. Copy (sym/it), number of items copied symmetrically/number of items attempted. Draw (0-3), number of drawings symmetrically copied. Bisect, mean directional bisection error for 16 lines presented on a single sheet. Bold values indicate presence of left neglect, as determined by: more than 10% greater omissions on left than on right in line crossing or star cancellation; asymmetry or omission of any item in copying; asymmetry of any drawing; mean bisection error exceeding 7 mm (>10% of average line half-length).*

Subjects

Twelve patients with left visual neglect following unilateral right hemisphere stroke participated. All patients were right-handed by self-report, and had been judged by rehabilitation staff, based on interpersonal interaction and/or standard screening (e.g. Mini Mental State Examination: Folstein, Folstein, & McHugh, 1975), to be cognitively able enough to give informed consent and to understand the task requirements. Unilateral brain damage was determined from clinical signs and/or clinical Computerised Tomography. Specialised neuropsychological testing focused on visual neglect, which was assessed using the line crossing, star cancellation and representational drawing sub-tests of the Behavioural Inattention Test (Wilson, Cockburn & Halligan, 1987), a five-item scene copying task adapted from Gainotti (1972), and a line bisection task adapted from Schenkenberg, Bradford, & Ajax (1980), which required the bisection of 16 horizontal lines, varying from 2-26 cm in length (average 14 cm), at a variety of positions on an A4 landscape sheet. A liberal inclusion criterion, the presence of left neglect on one or more of these diagnostic tasks, was applied. Details are given in Table 1.

Control data for the baseline bisection condition (no cues) were available from McIntosh and collagues (2005, Experiment 1). All of the control subjects were right-handed by self-report, except for two who were left-handed. The healthy control (HC) group (71.3 years; SD 9.1) was age-matched to the visual neglect (VN) group (69.5 years; SD 7.9).

Line bisection procedures

Horizontal lines, 3 mm thick, were printed individually in black ink on white A4 paper in landscape orientation. Four different line stimuli were created by the factorial combination of two locations of the left endpoint (L = -40 and -80 mm with respect to the page midline) with two locations of the right endpoint (R = +40 and +80 mm with respect to the page midline). Each patient performed a baseline version of the task, with no cues, in a separate session prior to the cued condition.

Endpoints line bisection with no cues. In the baseline session, each subject bisected 32 lines (eight repetitions for each line stimulus), presented individually, in a fixed randomised order. On each trial, the sheet was placed directly in front of the subject, with the page aligned centrally with the body. Subjects were required to mark the midpoint of the line with a pen held in the right hand, removing their hand from the table after each response, to prevent them adopting an invariant response position. The dependent measure on each trial was the response position (P), coded with respect to the page midline.

Endpoints line bisection with cues. The cued session was completed by the patient group only. Each line stimulus had one of eight capital letters (C, F, I, L, O, R, U, X) printed in 4 mm high, black Times New Roman font, 3 mm above the left or right end of the line, with its left or right edge respectively aligned with the line endpoint. Each patient bisected 64 lines, with each of the eight letters appearing once at each end of the four line stimuli (8*2*4 = 64). Lines were presented individually, in a fixed randomised order, with a short break after 32 trials. The patient was told that there would be a letter present on every trial, and that they must name the letter before making their bisection mark. If a patient was unable to find the letter on their own, the examiner would help them find the letter by moving a pen slowly along the line to its endpoint; this happened rarely, and only in the most severe cases of neglect. The endpoint cue was named correctly in every case, but in two trials the patient (VN09, VN12) marked the line before naming the cue; these two trials were excluded.

Endpoint weightings analysis

For each subject in each cueing condition (no cue, left cue, right cue), bisection responses, were coded as a horizontal position (P) with respect to the page midline. These raw P scores were then subjected to an endpoint weightings analysis (McIntosh et al., 2005)[1]. Conceptually, an endpoint weighting is simply the mean change in P associated with a shift in either endpoint between its two locations, expressed as a proportion of the size of the endpoint shift (40 mm). In practice, P was regressed upon the left and right endpoint locations according to a linear model, with the coefficient for the slope of the relationship between each endpoint and P giving the weighting for that endpoint. The regression equation is:

$$P = (dP_L \bullet L) + (dP_R \bullet R) + k$$

Where L and R are the line endpoint positions, dP_L and dP_R are the endpoint weightings, and k is a regression constant. Two composite measures, endpoint weightings bias (EWB) and endpoint weightings sum (EWS), are derived directly as follows:

$$EWB = dP_R - dP_L$$

$$EWS = dP_L + dP_R$$

[1] P was coded with respect to the page midline, irrespective of the line stimulus. But it is worth noting that, because the left and right endpoint locations in each experiment were, on average, symmetrical around the page midline, the mean value of P is equal to the mean bisection error with respect to the midpoint of the line.

Results

Endpoints line bisection with no cues. The left and right endpoint weightings (dP_L and dP_R) in the baseline (no cue) condition are shown, for every subject, in Figure 1a. Ideal performance would lie at the centre of the plot, with symmetrical endpoint weightings of 0.5. The control subjects cluster around this point; but the neglect patients show a very different pattern. Considering the data first with respect to the principal axes on the plot (dP_L and dP_R), almost all patients had a low weighting (< 0.5) for the left endpoint. The weighting for the right endpoint tended instead to exceed 0.5, though this was less universal. What *was* universal was that the right endpoint weighting was higher than that of the left. There was also a significant inverse relationship between endpoint weightings in the neglect group ($r = -.70$, $df = 10$, $p < .05$). The pattern of data is strikingly similar to that observed for the same task in a larger sample of patients (McIntosh et al., 2005, Figure 3a).

The data can also be considered with respect to the composite measures, EWB and EWS, represented by the diagonal axes in Figure 1a. The dashed line from lower left to upper right is the line on which the two weightings are equal (EWB = 0); points above this line indicate a higher weighting for the left endpoint and points below indicate a higher weighting for the right. The dotted line from lower right to upper left is the line on which the weightings sum to one (EWS = 1); points above this line indicate a sum of greater than one, and points below indicate a sum of less than one. Patients with left neglect occupy the quarter of the plot below both the dashed and dotted lines. If we interpret the endpoint weighting as a measure of attention allocated to that endpoint, then this would imply a rightward bias of attention (EWB > 0) combined with an overall reduction in attentional resources (EWS < 1).

Within this analytical framework, the core measure of neglect is EWB, as it indexes the lateral bias of attention. Figure 1b shows that EWB is strongly related to the standard measure of bisection error within the VN group (Spearman's $\rho = .85$, $p < .0005$), suggesting that these two indices measure substantially the same bias[2]. Nonetheless, there is a cleaner separation between patients and controls in terms of EWB than in terms of bisection error. The dotted lines in Figure 2b represent cut-offs for neglect on each measure. One patient produced a bisection

[2] Spearman's ρ is used because both measures are positively skewed (DBE severely so, with a skewness of 1.4), and because examination of this relationship in a larger sample of patients suggests that it flattens out as EWB approaches an effective maximum of 1 (McIntosh et al., 2005, Fig 3b). An EWB of 1 arises when the right endpoint weighting is 1 and the left endpoint weighting is zero, representing a patient that responds at a constant distance from the right endpoint of the line (see, e.g. Koyama et al., 1997). This may be the most extreme manifestation of neglect possible on the line bisection task.

error within the normal range yet showed a very clear asymmetry in terms of EWB; and a second patient with borderline classification according to bisection error was classified unambiguously with neglect by EWB. These subtle differences in sensitivity echo the observations of McIntosh and colleagues (2005), who found that 7 of 30 patients were classified with neglect by EWB but not by bisection error, with no instances of the reverse.

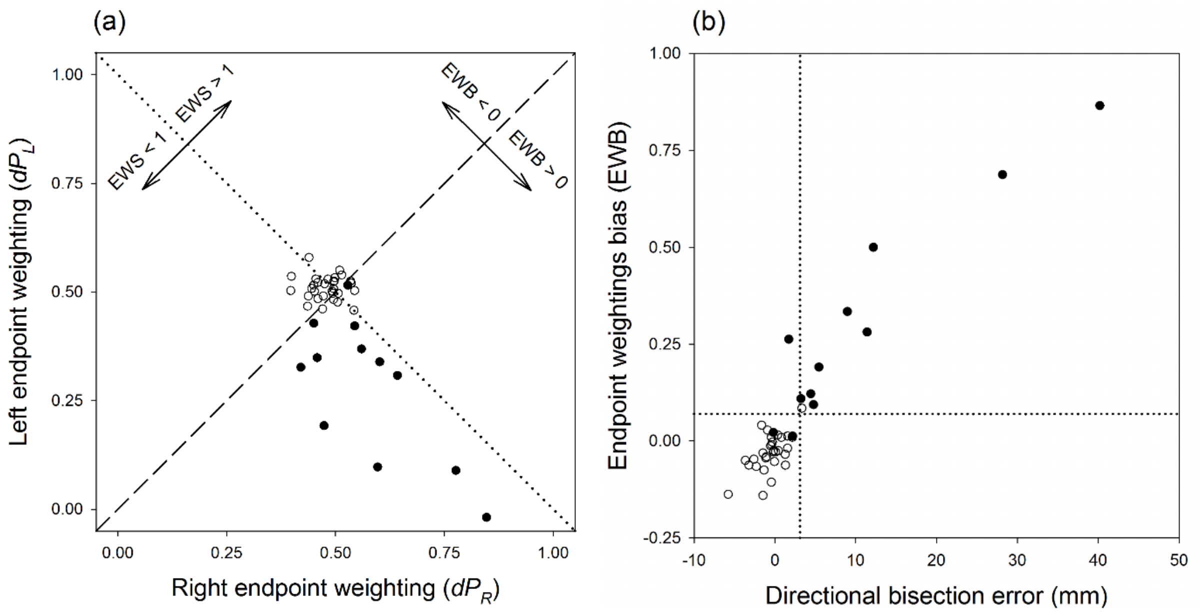

Figure 1. *Experiment 1. (a) Scatterplot relating right and left endpoint weightings for HC subjects (open circles) and VN patients (filled circles). Ideal performance would lie at the centre of the plot, with symmetrical endpoint weightings of 0.5. The dashed diagonal represents the line on which the two endpoint weightings are equal, so that the Endpoint Weightings Bias (EWB) equals zero. The dotted diagonal represents the line on which the Endpoint Weightings Sum (EWS) equals unity. (b) Scatterplot relating directional bisection error and endpoint weightings bias for HC subjects (open circles) and VN patients (filled circles). The dotted lines represent operational cut-offs for left neglect on each measure at 2.08 standard deviations above the control group mean, using the modified t-criterion for small control samples (two-tailed α = .05) (Crawford & Howell, 1998).*

If EWB indexes the lateral bias of neglect more effectively than does directional bisection error, then we might also expect that it will correlate more closely with cancellation and other core measures of neglect. The data do lie in this expected direction, but will not be addressed here, because the visual neglect group for this cueing experiment is a sub-sample of a larger cohort (n=50) of right-brain damaged patients who have completed the baseline (uncued) version of the endpoints line bisection task alongside other conventional tests. The relationships of interest can be estimated more reliably in the full sample, reported separately (McIntosh, 2017).

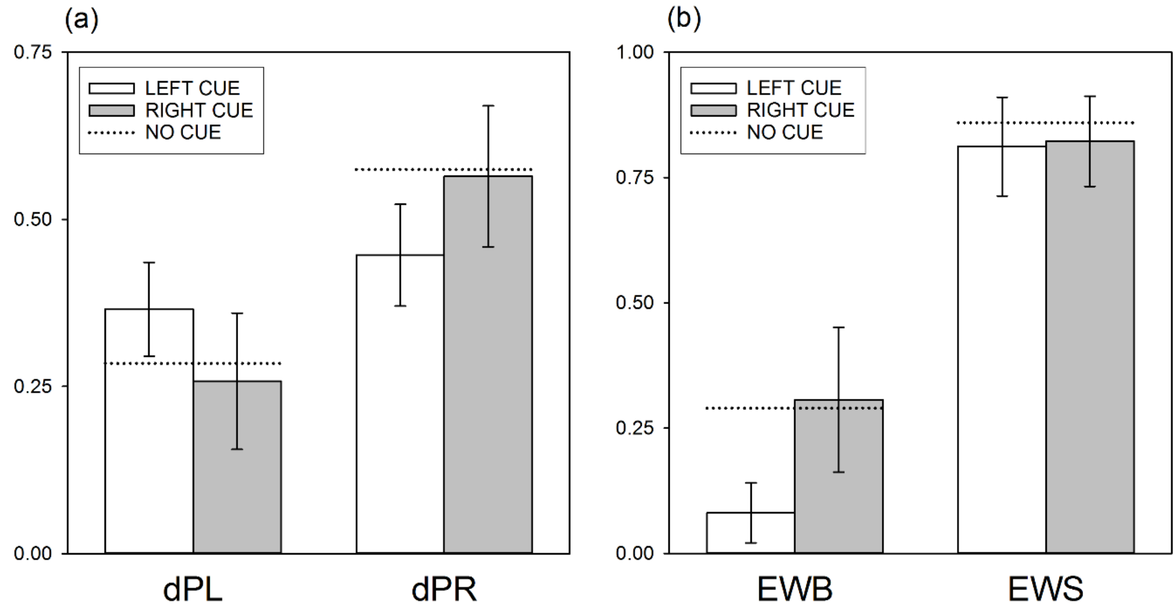

Figure 2. *(a) The effect of line-end cueing on left and right endpoint weightings (dPL and dPR) for the VN group. (b) The same data, re-presented in terms of the composite measures, endpoint weightings bias (EWB) and endpoint weightings sum (EWS). Error-bars depict 95% confidence intervals for within-subjects designs (Cousineau, 2005, with correction suggested by Morey, 2008).*

Endpoints line bisection with cues. Having replicated the inverse relationship between endpoint weightings across patients, we can next evaluate whether it holds *within patients*, using line-end cues to manipulate the lateral allocation of attention Riddoch & Humphreys, 1983. The effect of cueing on endpoint weightings is depicted in Figure 2a. There were no substantial departures from normality for any condition (or in the distributions of the differences representing relevant interaction terms), and the data were judged suitable for repeated-measures ANOVAs[3]. First, for the data in Figure 2a, ANOVA confirmed a significant interaction of cue side by endpoint weighting [$F_{1,11}$ = 19.1, $p < .005$, $\eta^2_p = .64$]: a left cue increases the weighting for the left endpoint and simultaneously decreases the weighting for the right. Comparison against the weightings from the no cue baseline (dotted lines) suggest that the effect is driven exclusively by the left cue, as the right cue induces no discernible change from baseline. This would imply that neglect patients already attend as fully as they

[3] This analysis choice is unimportant for the conclusions. Exactly the same pattern of significant and non-significant findings is obtained by applying Wilcoxon signed rank tests to each relevant pairing of conditions.

can to the right endpoint in the uncued task, so are unaffected by explicit cueing to this side. Their deficit is for attention to the left, and this is ameliorated by the forced report of left cues. Attention to the right endpoint simultaneously falls by a corresponding amount, confirming the predicted antagonism between endpoint weightings.

In Figure 2b, the same data are re-presented in terms of composite measures, EWB and EWS. A repeated-measures ANOVA showed a significant interaction of cue side by composite measure [$F_{1,11} = 20.5$, $p < .005$, $\eta^2_p = .65$]: a left cue reduces EWB toward symmetry (zero), but cueing has no influence upon EWS, exactly as predicted.

Additional observations. In a more exploratory vein, Figure 3 shows overlaid scatterplots relating EWB in the cueing conditions to baseline EWB. Some observations can be offered. First, the linear function relating performance in the right cue condition to that in the no cue condition was close to a line of identity, bolstering the idea proposed above that neglect patients already attend fully to the right endpoint in the uncued baseline task. Second, the impact of left cueing generally increases with the severity of neglect; the correlation between baseline EWB and the reduction in EWB for left compared with right cueing was substantial (Spearman's $\rho = .72$). Cueing benefit thus scales grossly with deficit, though not enough to bring all patients to the same level: the three patients with the most severe baseline neglect were still the most impaired even in the left-cue condition. These patients were, by decreasing severity, VN12, VN11 and VN02. All three showed neglect on every screening task, and were diagnosed with visual field defects (Table 1). This is consistent with the idea that neglect can be especially severe when it co-exists with visual field deficits, because the former prevents compensation for the latter. Finally, in one patient (VN03), the directionality of EWB was apparently reversed by left end-cueing, relative to the no cue baseline.

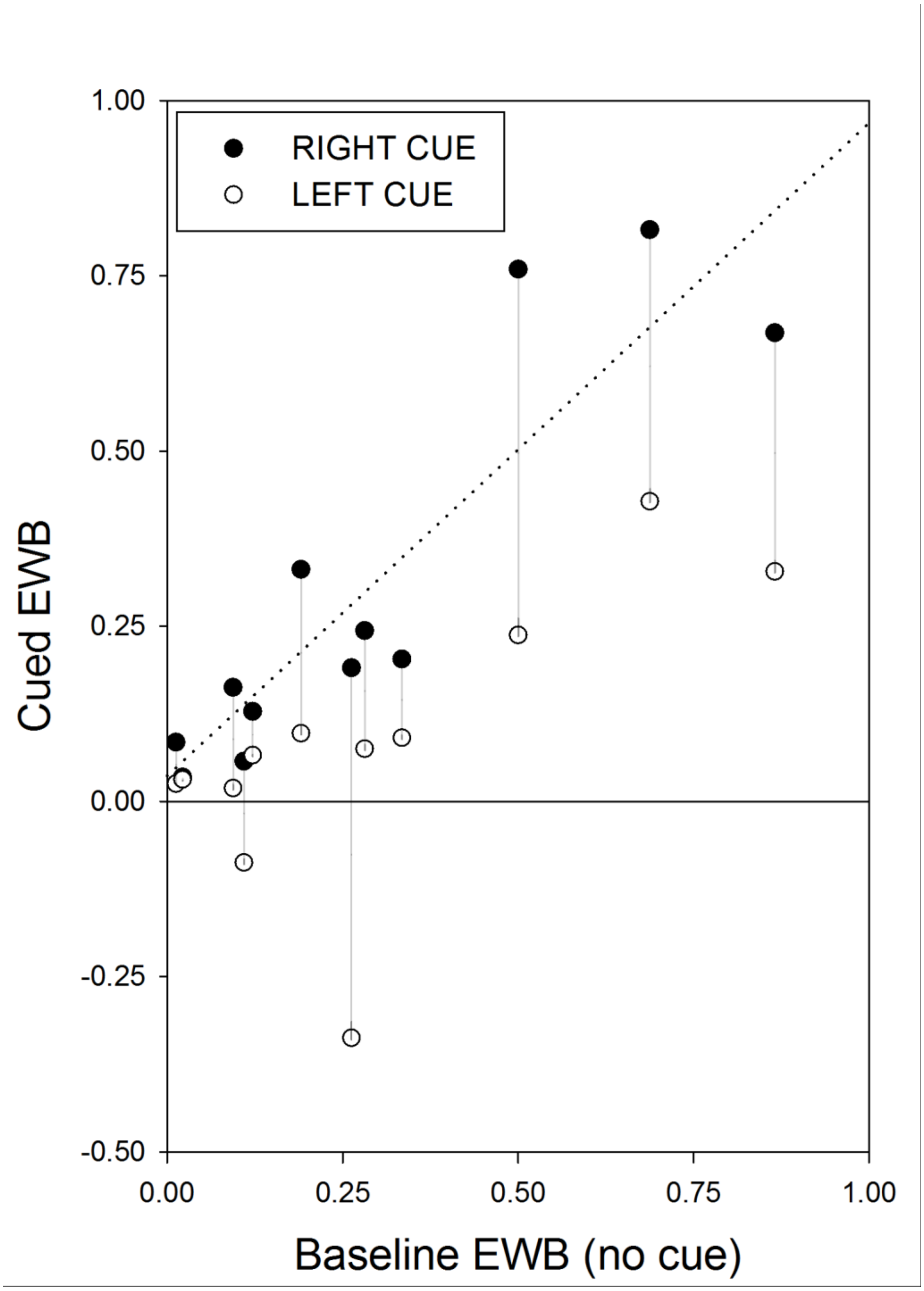

Figure 3. *Overlaid scatterplot relating baseline EWB (no cue) to EWB under left and right end-cueing. The dotted line indicates the best-fitting straight line relating the right cue condition to baseline, and it is close to identity (Y = 0.04 + 0.93X). The impact of left end-cueing, represented by the length of the grey drop lines, tends to increase with the severity of the baseline deficit.*

Discussion

This study examined a key prediction of the endpoint weightings analysis of line bisection behaviour in neglect: that manipulations drawing attention to one end of the line would increase the weighting for that endpoint, and simultaneously decrease the weighting for the other (McIntosh et al., 2005). Attention was manipulated using the forced-report cueing technique of Riddoch & Humphreys (1983). The prediction was confirmed, but consideration of cued performance relative to a baseline block suggested an interesting asymmetry. Left end-cueing increased the weighting for the left endpoint, and reduced the weighting for the right by a corresponding amount; but right-end cueing had no influence, presumably because attention was already fully biased toward to this of the line by virtue of the patients' neglect. The data confirm an antagonistic relationship between endpoint weightings, consistent with the idea that they represent the sharing of a finite resource between left and right.

The endpoint weightings analysis offers an alternative model for the line bisection task, with a novel set of dependent and independent variables. The traditional analysis for this task prioritises the deviation of the response from the objective centre of the line, a static measure for a given stimulus. This standard approach has been used in patients with neglect to study how bisection error varies with line length (Bisiach, Bulgarelli, Sterzi, & Vallar, 1983; Butter, Mark, & Heilman, 1988; Halligan & Marshall, 1989; Halligan & Marshall, 1988; Marshall & Halligan, 1989; Nichelli, Rinaldi, & Cubelli, 1989), and with the spatial position of the line centre (Heilman & Valenstein, 1979; Nichelli et al., 1989; Schenkenberg et al., 1980); and similar factors have been investigated in healthy subjects (Jewell & McCourt, 2000; McCourt & Jewell, 1999). The endpoint weightings analysis, by contrast, prioritises the first derivative of bisection behaviour: that is, how the spatial position of the response varies with changes in the line endpoint positions. These analyses choose different terms to describe bisection behaviour, yet it is possible to translate between them. Simple algebra shows that EWB is numerically equal to (twice) the slope of the function relating bisection error to line length in the standard model, whilst EWS is equal to (one plus) the slope of the function relating bisection error to spatial position (McIntosh et al., 2005). This formal equivalence means that the question is not whether the alternative model is more correct than the traditional one, but whether it is more useful.

One indicator of usefulness would be the ability to generate testable predictions. A novel prediction generated from the endpoints weightings framework was that of antagonistic endpoint weightings (McIntosh et al., 2005, Section 4.3). This antagonism entails that manipulations of lateral attention should influence EWB without altering EWS, and this prediction has been confirmed in the present study. If we are willing to suppose that an endpoint weighting indexes the amount of attention allocated to that end of the line, then the explanation of these effects is obvious: cueing affects the lateral distribution of attention (EWB) but does not change the total amount available for the task (EWS). Recasting these findings in terms of the traditional approach, we could instead say that left end-cueing reduces the slope of the line length effect without affecting the slope of the spatial position effect. It might be possible to accommodate these findings within a traditional framework, but it seems unlikely that the explanation would have the intuitive appeal of the endpoint weightings account given above. And, crucially, any such explanation would be post-hoc, since a century of research in the traditional framework had not generated this prediction.

Another indicator of usefulness would be sensitivity to lateral biases of behaviour, which is what the line bisection task is generally held to measure. In this respect too, the endpoint weightings framework may outperform the standard model. Its core measure (EWB) is more sensitive to neglect than is bisection error, and it may similarly be more sensitive to the subtle *leftward* bisection bias often seen in healthy subjects (Jewell & McCourt, 2000; McCourt & Jewell, 1999). We can see this in the control group's performance in the baseline task: the mean leftward bias was significant in terms of EWB (-0.03, 95% CI [-0.05, -0.01], but not in terms of bisection error (0.54 mm, 95% CI [-1.23, 0.15]) (these control data are the same as those reported in McIntosh et al., 2005). Tellingly, Halligan and Marshall, who made extensive explorations of the dynamics of neglect bisection behaviour, did come to champion the slope of the line length effect (≡ EWB) as a sensitive measure that can reveal rightward biases even in some patients who make accurate or leftward bisections (Halligan & Marshall, 1988; Marshall & Halligan, 1989). However, the special value of this measure was not argued *a priori*, and their interpretation of the amplified line length effect in neglect was somewhat contrived, depending on an inflated Weber fraction for horizontal extent and a right-to-left scanning strategy. This hypothesis has not been corroborated by subsequent empirical work (Ishiai, Koyama, Seki, Hayashi, & Izumi, 2006; see also McIntosh, 2006). From the perspective of the endpoint weightings model, by contrast, the relevance of the line length effect as a measure of bias is inescapable, because EWB is literally the difference between the weightings given to the two ends of the line.

A third degree of usefulness is the ability to give a richer description of relevant behaviour. On this point, it can be argued that the weightings analysis affords insight into aspects of performance invisible to a standard analysis. Directional bisection error can, at best, index a net asymmetry of attention; but an endpoint weighting has an ideal level of 0.5, so may additionally tell us whether each side receives too much or too little attention. For instance, the present control sample bisected (non-significantly) left of centre, consistent with *relative* over-attention to the left; but the endpoint weightings suggest that this has less to do with overweighting the left than with under-weighting the right, as dP_L is close to ideal (0.51, 95% CI [0.50, 0.52]) whilst dP_R is low (0.48, 95% CI [0.47, 0.49]). This specific pattern requires replication, but the general point is that endpoint weightings may index absolute and not just relative levels of attention. This in turn suggests that the sum of the endpoint weightings (EWS) may be another useful composite measure. EWS is characteristically low in patients with neglect, yet is uncorrelated with the primary lateral bias (McIntosh et al., 2005). If we propose EWS as a measure of total attention, then it should be modifiable by manipulations of arousal (e.g. Robertson, Mattingley, Rorden, & Driver, 1998), and patients with impaired arousal should show the greatest shortfall in EWS. If these predictions are upheld, it would imply that the line bisection task is sensitive not only to lateral biases of attention, but separately to non-lateralised aspects of impairment (Husain, 2005; Robertson, 1993).

The endpoint weightings model is also unifying, because it makes minimal assumptions about how the task is executed. Koyama et al. (1997) proposed that the bisection behaviour of patients with severe neglect might be qualitatively distinct from that of patients with milder biases. Based on their impression that severe neglect patients responded at a constant distance from the right end of the line, they inferred that these responses were made with reference to the right endpoint alone. They argued that it was inappropriate to consider these patients within the same framework as milder patients, for whom line length was a relevant factor. The endpoints model, however, makes no assumptions about the processing of line length, so offers a common framework to describe bisection behaviour in severe neglect ($\sim$ EWB $>$ 0.5), milder neglect ($\sim$ 0.5 $<$ EWB $>$ 0.07) and no neglect ($\sim$EWB $<$ 0.07), without excluding the possibility of distinct processes of bisection at different levels of severity.

Although the endpoint weightings model is itself theoretically neutral, the present data do have implications for theories of neglect. The reduction of neglect with forced report of left cues is consistent with Riddoch & Humphreys' (1983) classic findings, and thus with their suggestion that neglect results from a failure of *automatic* orienting of attention. The present data additionally show that left cueing does not make up for a deficit by boosting attention, but instead promotes a redistribution of attentional resources: the extra weight given to the left end of the line is deducted from that given to the right, reducing the attentional bias, and even sometimes reversing it (see Figure 3). This supports an account of line bisection in terms of competitive attentional allocation between the two sides of the line (e.g. Urbanski & Bartolomeo, 2008), rather than an account that proposes an underlying distortion of the medium for spatial representation (Bisiach, Pizzamiglio, Nico, & Antonucci, 1996; Bisiach, Bulgarelli, Sterzi, & Vallar, 1983). An attentional competition account would not be specific to the bisection task, but could apply widely across the symptoms of neglect, as originally envisaged by Kinsbourne (1993).

The endpoint weightings model is not a theory of neglect, but it may be a uniquely *useful* framework for administering and analysing bisection tasks. Recast within this novel framework, bisection is an excellent task to probe the competitive bias of attention in neglect, and perhaps also to measure overall attentional resources (whether it can tell us anything reliable about length estimation in neglect is still an open question). Clearly, if this approach can make the line bisection task a more sensitive and valid index of attentional allocation, and can also assess generalised attention, then it may be of potential clinical utility as well as research significance. But usefulness is useless unless it is used. In the twelve years since this model was proposed, no study until now has adopted it. On the other hand, one group has explicitly cited its logic, explaining wheelchair navigation, and the effect of spatial cueing on collisions in neglect, in terms of the weighting accorded to objects on the left and right (Punt, Kitadono, Hulleman, Humphreys, & Riddoch, 2008, 2011). It is hoped that the present study, which illustrates the potential power of this approach, will encourage its further adoption for the investigation of line bisection and related behaviours. If so, to paraphrase Mozer, Halligan, & Marshall (1997), it may not yet be the end of the line for this simple, versatile, and informative task.

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