Neuropsychologia 106 (2017) 146–158

Contents lists available at ScienceDirect

Neuropsychologia

journal homepage: www.elsevier.com/locate/neuropsychologia

Weight and see: Line bisection in neglect reliably measures the allocation of attention, but not the perception of length

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ARTICLE INFO

Keywords:
Attention
Unilateral neglect
Line bisection
Cancellation

ABSTRACT

Line bisection has long been a routine test for unilateral neglect, along with a range of tests requiring cancellation, copying or drawing. However, several studies have reported that line bisection, as classically administered, correlates relatively poorly with the other tests of neglect, to the extent that some authors have questioned its status as a valid test of neglect. In this article, we re-examine this issue, employing a novel method for administering and analysing line bisection proposed by McIntosh et al. (2005). We report that the measure of attentional bias yielded by this new method (EWB) correlates significantly more highly with cancellation, copying and drawing measures than the classical line bisection error measure in a sample of 50 right-brain damaged patients. Furthermore when EWB was combined with a second measure that emerges from the new analysis (EWS), even higher correlations were obtained. A Principal Components Analysis found that EWB loaded highly on a major factor representing neglect asymmetry, while EWS loaded on a second factor which we propose may measure overall attentional investment. Finally, we found that tests of horizontal length and size perception were related poorly to other measures of neglect in our group. We conclude that this novel approach to interpreting line bisection behaviour provides a promising way forward for understanding the nature of neglect.

1. Introduction

Horizontal line bisection is a simple task used widely in the diagnosis and study of visual neglect (Axenfeld, 1915; Schenkenberg et al., 1980). The brain-damaged patient is asked to mark the midpoint of a presented line, and substantial deviation from the true centre is taken to indicate neglect for the opposite side of space. This task requires minimal materials, is quick to administer, and in its classical form of analysis, in which an average directional error is taken, yields a single continuous measure of asymmetry. In developing their standardised battery of diagnostic tests for neglect, Halligan et al. (1989) included line bisection as a core test, along with target cancellation, figure copying and free drawing.

A common assumption has been that line bisection is a test of length perception, tapping into the visuospatial experience of the patient (e.g. Schenkenberg, 1980). Under this assumption, the average directional bisection error is an estimate of the patient's subjective midpoint, and therefore of any perceptual asymmetry. [It is true that during the 1990s some research groups suggested that extreme bisection errors can sometimes reflect a motoric rather than (or in addition to) a perceptual bias (Bisiach et al., 1990; Bisiach et al., 1998; Coslett et al., 1990; Harvey et al., 1995a, 1995b; Milner et al., 1993; Tegnér and Levander, 1991). Nonetheless, average directional error was always the standard measure taken to characterise behaviour.]

1.1. A novel approach

There is an alternative way to elicit and analyse bisection data, one that emphasizes the trial-to-trial variations of behaviour rather than taking an average score. This novel approach, proposed by McIntosh et al. (2005) avoids the assumption that the patient's response reflects a meaningful subjective midpoint; that is, no special status is given to the deviation from the true midpoint (i.e. directional bisection error). Instead, as illustrated in Fig. 1a, each response is coded simply as a horizontal coordinate relative to a fixed environmental location (such as the midline of the sheet). The analysis then focuses on how this response position varies from trial-to-trial as a consequence of changes in the positions of the left and right endpoints of the line. Across trials, the left and right endpoint positions are manipulated orthogonally, for instance using a set of four stimulus lines created by crossing two possible

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http://dx.doi.org/10.1016/j.neuropsychologia.2017.09.014
Received 7 July 2017; Received in revised form 6 September 2017; Accepted 13 September 2017
Available online 18 September 2017

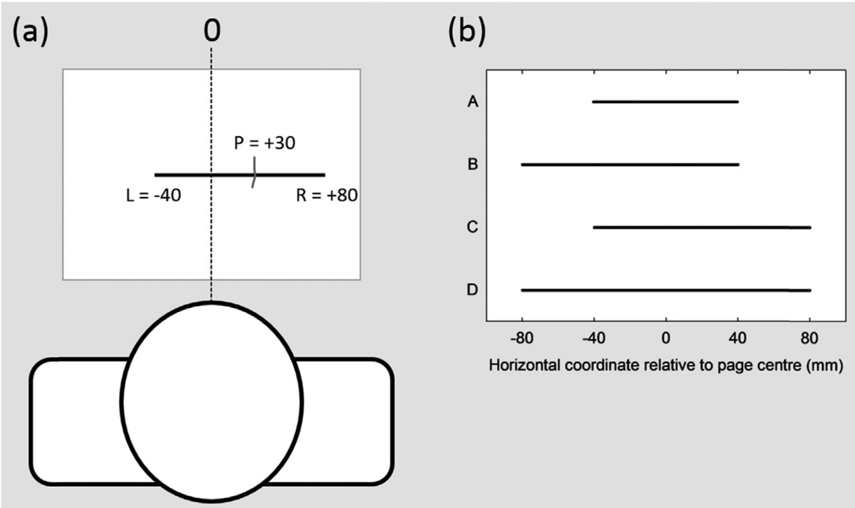

Fig. 1. The endpoint weightings format of line bisection. (a) The stimulus sheet with a single line is placed directly in front of the patient, who is asked to bisect the line by marking a position (P). In the traditional task analysis, the line in this example would be considered as 120 mm long, displaced 20 mm towards the right hemispace, and the patient's response would be scored as a +10 mm deviation from the true midpoint of the line. In the endpoint weightings analysis, the positions of the response (P) and of the left (L) and right (R) endpoints are coded as horizontal coordinates relative to a fixed environmental reference, in this case the centre of the page (0). The patient in this example has responded at +30 mm, with L at −40 mm and R at +80 mm. (b) In a basic version of the endpoints line bisection task, a set of stimulus lines (A-D) is generated by crossing two positions of L (−40, −80) with two positions of R (+40, +80). Each line is presented individually, with eight repetitions for each stimulus line. The analysis focuses on how P varies as a consequence of changes in L (lines A & C vs B & D) or changes in R (lines A & B vs C & D). See Methods for full details.

locations of each endpoint (Fig. 1b). The influence of each endpoint on the response (the 'endpoint weighting') can then be calculated: the right endpoint weighting is the average change in the response that accompanies the change in the right endpoint, expressed as a proportion of the endpoint change, and vice-versa for the left endpoint.

If the bisection task were performed perfectly, then a shift in one endpoint location would be accompanied by a shift in the response half as large in the same direction (e.g. moving the right endpoint to the right by 40 mm would cause the bisection response to shift to the right by 20 mm). Perfect performance would thus yield symmetrical right and left endpoint weightings of 0.5. McIntosh et al. (2005) reported that a group of 30 healthy older participants approached this ideal, albeit with a slightly but significantly higher weighting for the left endpoint than for the right (0.51 vs 0.48). In contrast, in 30 patients with left neglect, the left endpoint weighting was almost always lower than the right, indicating that the response was more influenced by the right endpoint than by the left. In extreme cases, the left endpoint weighting approached zero and the right endpoint weighting approached one, meaning that the response essentially maintained a constant distance from the right endpoint (cf. Koyama et al., 1997). These patterns have now been replicated in a further 12 patients with left neglect (McIntosh, 2017).

This novel analysis of line bisection has some noteworthy properties. First, a simple measure of lateral asymmetry, the endpoint weightings bias (EWB), given by the subtraction of the left endpoint weighting from the right endpoint weighting, identifies neglect in a higher proportion of patients than does the standard measure of bisection error (McIntosh et al., 2005; McIntosh, 2017). That is, EWB can expose an under-weighting of the left relative to the right endpoint in patients who bisect within normal limits, or even in patients who bisect abnormally leftwards. Similarly, the linear combination of these left and right endpoint weightings accurately predicts that some left neglect patients will make leftward ("crossover") bisections for short lines and/or for lines presented toward the right side of the sheet (McIntosh et al., 2005). In other words, some apparently 'anomalous' bisections are no longer anomalous when viewed within an endpoint weightings framework. As originally articulated by Kinsbourne (1993), rightward *or* leftward errors of bisection can result from a lack of awareness of the left endpoint of the line (p. 72).

A second noteworthy property is that, because the ideal value of each endpoint weighting is known (0.5), we may state whether each endpoint receives too much or too little weight in absolute terms. It is therefore potentially informative to calculate the total weighting across the two endpoints: the endpoint weightings sum (EWS). Healthy older participants score close to one on this index, but patients with neglect very often score lower (McIntosh et al., 2005; McIntosh, 2017). If we propose that an endpoint weighting reflects the attention allocated to each side of the line, then a reduced EWS would indicate reduced overall attentional allocation. Regardless of its precise theoretical interpretation, EWS is a non-lateralised measure that can again discriminate patients from controls (McIntosh et al., 2005). These two measures, EWB and EWS, fall readily from the 'endpoint weightings' format of the line bisection task, in which left and right endpoint positions are varied independently.[1]

1.2. Relation to other measures of neglect

There has been disagreement over the extent to which the classical directional bisection error correlates with other measures of neglect. Initially, Halligan et al. (1989) reported that bisection performance correlated strongly with their other core tests ($r = 0.67$ correlation with star cancellation; 0.73 with copying; 0.63 with drawing). A Principal Components Analysis (PCA) found that all core tests loaded strongly (0.85) onto a single factor accounting for 73% of the total variance, leading to the conclusion that visual neglect is – to a large extent – a single phenomenon. Since then, however, this conclusion has been seriously disputed, even by Halligan and Marshall (1992) themselves, who went so far as to declare left visual neglect 'a meaningless entity'.

In particular, the less than perfect relationship between bisection and cancellation has been a focus of interest. Binder et al. (1992) reported a correlation of only $r = 0.39$ amongst 21 (of 34) right-brain damaged patients who met criteria for neglect on one or both tasks of bisection and letter cancellation. Later studies have yielded diverse estimates for the correlation between line bisection and various versions of target cancellation in neglect, ranging from $r = 0.37$ (Guariglia et al., 2014) to $r = 0.76$ (Molenberghs and Sale, 2011). This last correlation, however, was driven by three patients with strong asymmetries on both tasks: a more appropriate nonparametric correlation for their tabulated data would have returned a much less impressive Spearman ρ of only 0.26. Other estimates include $r = 0.40$ (Sperber and Karnath, 2016), and $r = 0.49$ (Ferber and Karnath, 2001), while Azouvi et al. (2002) reported a correlation of only 0.19 for 5 cm lines, but of 0.62 for 20 cm lines. These estimates, though varied, are weaker than

[1] McIntosh et al. (2005) noted, however, that EWB is numerically equal to (twice) the slope of the function relating directional bisection error to line length in the classical task analysis, and EWS is equal to (one plus) the slope of the function relating bisection error to spatial position. Therefore, EWB might be able to be estimated retrospectively for datasets where line length has been varied systematically, and EWS where the position of the line on the sheet has been varied.