Vision Research 111 (2015) 1–12

Contents lists available at ScienceDirect

Vision Research

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

Spatial distortions in localization and midline estimation in hemianopia and normal vision

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ARTICLE INFO

Article history:
Received 7 January 2015
Received in revised form 11 March 2015
Available online 11 April 2015

Keywords:
Hemianopia
Hemianopic Line Bisection Error
Pseudoneglect
Bisection
Space perception
Peripheral localization

ABSTRACT

Studies have shown that individuals with hemianopia tend to bisect a line toward their blind, contralesional visual field, termed the hemianopic line bisection error (HLBE). One theory proposes that the HLBE is a perceptual distortion resulting from expansion of the central region of visual space. If true, perceptual expansions of the central regions in the *intact* hemifield should also be present and observable across different tasks. We tested this hypothesis using a peripheral localization task to assess localization and midpoint estimation along the horizontal axis of the visual field. In this task, participants judged the location of a target dot presented inside a Goldmann perimeter relative to their perceived visual field boundary. In Experiment 1, we tested neurologically healthy participants on the peripheral localization task as well as a novel midpoint assessment task in which participants reported their perceived midpoint along the horizontal axis of their left and right visual fields. The results revealed consistency in individual biases across the two tasks. We then used the peripheral localization task to test whether two patients with hemianopia showed a selective expansion of central visual space. For these patients, three axes were tested: the spared temporal horizontal axis and the upper and lower vertical axes. The results support the notion that the HLBE is due to expansion of perceived space along the spared temporal axis. Together, the results of both experiments validate the use of these novel paradigms for exploring perceptual asymmetries in both healthy individuals and patients with visual field loss.

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1. Introduction

Hemianopia, or a binocular loss of vision in one half of the visual field, occurs following unilateral damage to the optic tract, optic radiations, or striate and/or extrastriate cortical areas (Blumenfeld, 2002). It is most often caused by stroke or trauma (Zhang et al., 2006). One characteristic of acquired hemianopia is the Hemianopic Line Bisection Error (HLBE), or the tendency to bisect lines in the direction of the *impaired* (contralesional) hemifield. This tendency is the opposite to that commonly observed in patients with unilateral visual neglect, who tend to bisect lines away from the impaired hemifield, showing an ipsilesional bias (Barton & Black, 1998; Liepmann & Kalmus, 1900).

Though the HLBE is well documented, there are several unresolved issues that have inspired recent research in this area (Kerkhoff & Schenk, 2011; Kuhn et al., 2012; Mitra et al., 2010; Ogun, Viswanathan, & Barton, 2011; Schuett, Dauner, & Zihl, 2011; Zihl et al., 2009). Some studies have reported that the HLBE is found only in patients with lesions in extrastriate visual areas (Schuett, Dauner, & Zihl, 2011; Zihl et al., 2009), although other research that simulated hemianopia in neurologically healthy participants suggests that the HLBE results from loss of vision within a large region of visual space, and does not only arise with hemianopia due to extrastriate lesions (Mitra et al., 2010; Ogun, Viswanathan, & Barton, 2011). Other work has investigated the development of a "pseudo-fovea" (i.e., eccentric fixation) in hemianopia, similar to those observed in patients with central field loss following macular degeneration (Cheung & Legge, 2005; Crossland et al., 2005), and the role that shifts in spatial attention

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http://dx.doi.org/10.1016/j.visres.2015.03.022
0042-6989/Published by Elsevier Ltd.

play in the HLBE (Kuhn et al., 2012). While spatial cueing has been shown to modulate line bisection errors in neurologically healthy individuals, with the perceived midpoint of a line shifted toward the cue location (Harvey et al., 2000; McCourt, Garlinghouse, & Reuter-Lorenz, 2005; Nichelli & Rinaldi, 1989; Toba, Cavanagh, & Bartolomeo, 2011), a spatial cueing study in patients with hemianopia failed to find significant modulations in the direction or magnitude of the HLBE (Kuhn et al., 2012). The results of Kuhn et al. (2012) also provide evidence against a possible contribution of a preferred eccentric retinal locus to the HLBE.

By definition, patients with hemianopia are only able to perceive lines within one hemifield. Thus, in order to assess the midpoint of a line, patients with hemianopia must either be able to scan a line over time or the entirety of the line must be presented to the intact hemifield. If patients scan across a line, they will view all or part of the line within the intact hemifield at a given moment. If fixation is attempted toward the middle of the line, then patients must maintain and utilize a short-term representation of the line length that is no longer visible within the area of field loss. Alternatively, patients could fixate one end of the line, allowing them to perceive the line entirely within the intact hemifield and perform calculations on line length and midpoint based on this viewpoint. If this latter approach is taken then one potential complication that arises is differences in perceptual sensitivity and potential size asymmetries that may exist as a function of eccentricity. This possibility was assessed by Nielsen, Intriligator, and Barton (1999) in a study of neurologically healthy participants who were asked to judge the midpoint of horizontal and vertical lines while fixating on one end or the other. Results of three experiments showed a centripetal bias, or a tendency to perceive the midpoint closer to the point of fixation than it actually was by approximately 2.6% of the line length. This finding suggests a relative expansion of visual space in the central versus peripheral regions of the visual field. Further analysis suggests that the pattern of results is more consistent with participants determining the midpoint of lines through "angle bisection" rather than line bisection as the true angular midpoint is located more peripherally, though a central expansion was still present even when the midpoint was calculated in terms of degrees of eccentricity. While the centripetal bias is directionally consistent with the over-representation of the central visual field observed in early retinotopic visual areas (Horton & Hoyt, 1991), the magnitude of the bias observed in this sample suggests that cortical magnification in early retinotopic visual areas alone cannot predict the magnitude of bias that was observed. Indeed, it has been suggested by other researchers that differences in attentional distribution or attentional scanning over a large region of space contribute to the centripetal biases observed when lines are presented within one hemifield (McCourt, Garlinghouse, & Slater, 2000).

The presence of a space-based central bias in neurologically healthy participants has been confirmed in another series of studies that manipulated the relative position of greyscale stimuli (Nicholls et al., 2004; Orr & Nicholls, 2005). Greyscale stimuli have been increasingly used instead of line bisection stimuli to assess "pseudoneglect", which refers to the tendency for neurologically healthy individuals to bisect lines slightly to the left of center (or in this case perceive the same gradient stimulus as "darker" when presented on the left side). Interestingly, the results of the study by Orr and Nicholls (2005) dissociated a leftward bias, pseudoneglect, from the foveal bias, suggesting that the foveal expansion observed in the study by Nielsen, Intriligator, and Barton (1999) is distinct from the leftward biases observed in most bisection studies of pseudoneglect.

One of the goals of the present study was to determine the degree to which the two tasks used are sensitive to perceptual distortions that vary across individuals and hemifields in neurologically healthy participants (i.e. pseudoneglect). We used both a peripheral localization task as well as a novel bisection task that measures the degree to which individuals can locate the midpoint of their right or left visual field (Visual Axis Midpoint Assessment task, VAMA). We then compared estimated midpoints across the peripheral localization and VAMA tasks to determine whether they were measuring similar localization abilities. These tasks were then used to study spatial biases in patients with hemianopia.

Although studies of spatial biases in hemianopia have focused primarily on line bisection tasks, numerous other paradigms have been developed to study peripheral localization (Adam et al., 1993; Fortenbaugh & Robertson, 2011; Fortenbaugh et al., 2012; Müsseler et al., 1999; Temme, Maino, & Noell, 1985; van der Heijden et al., 1999) and the application of these paradigms may help to provide further insight into the perceptual processes leading to the HLBE. In particular, given the existence of perceptual biases in neurologically healthy individuals that may be object-based (Orr & Nicholls, 2005), it is of interest to employ other paradigms that assess perceived location in the absence of external objects to determine whether the HLBE represents an expansion of central visual space beyond that observed in neurologically healthy participants under similar experimental conditions.

In a previous series of experiments (Fortenbaugh et al., 2012), we demonstrated that in the absence of any external object boundaries, neurologically healthy individuals mislocalize briefly-presented target dots toward the periphery of their visual field, indicating an expansion of central visual space similar to that observed by Nielsen, Intriligator, and Barton (1999). We also found greater expansion of central visual space at near compared to far eccentricities. We measured peripheral localization of target dots presented in a Goldmann perimeter by collecting verbal magnitude estimates in relation to perceived visual field extent (see also Temme, Maino, & Noell, 1985). The Goldmann perimeter is a self-illuminated half-dome that allows manual presentation of targets at locations up to 90° of visual angle in any direction and has several advantages for peripheral localization studies, including (1) the absence of any external object boundaries, such as the edges of a computer monitor, (2) the ability to present targets at any visual field location while simultaneously visually monitoring the fixation of participants, and (3) the use of the same visual environment and stimuli to measure peripheral localization as well as visual field extent. In the present study we address two questions. In Experiment 1 we test the degree to which our peripheral localization task is sensitive to hemifield asymmetries in neurologically healthy individuals. In Experiment 2 we assess peripheral localization performance in two patients with hemianopia and show spatially specific distortions that are consistent with the HLBE.

2. Experiment 1: peripheral localization in neurologically healthy participants

2.1. Methods

2.1.1. Participants

Eleven neurologically healthy normal-vision undergraduate volunteers completed the experiment (7 females; mean age: 21.2 ± 2.4 years). All participants reported 20/20 visual acuity, either without optical correction or with optical correction by contact lenses. Participants were excluded if they wore eyeglasses, as these artificially restrict the visual field (Steel, Mackie, & Walsh, 1996). All participants reported no history of eye diseases or neurological disorders of any kind. All procedures were approved by the Committee for the Protection of Human Subjects at the University of California, Berkeley, and followed the tenets of the