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Line bisection in simulated homonymous hemianopia

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ABSTRACT

Hemianopic patients make a systematic error in line bisection, showing a contra-lesional bias towards their blind side, which is the opposite of that in hemineglect patients. This error has been attributed variously to the visual field defect, to long-term strategic adaptation, or to independent effects of damage to extrastriate cortex. To determine if hemianopic bisection error can occur without the latter two factors, we studied line bisection in healthy subjects with simulated homonymous hemianopia using a gaze-contingent display, with different line-lengths, and with or without markers at both ends of the lines. Simulated homonymous hemianopia did induce a contra-lesional bisection error and this was associated with increased fixations towards the blind field. This error was found with end-marked lines and was greater with very long lines. In a second experiment we showed that eccentric fixation alone produces a similar bisection error and eliminates the effect of line-end markers. We conclude that a homonymous hemianopic field defect alone is sufficient to induce both a contra-lesional line bisection error and previously described alterations in fixation distribution, and does not require long-term adaptation or extrastriate damage.

Line bisection is a task most commonly used to demonstrate an abnormal spatial bias in patients with hemispatial neglect, with subjects tending to bisect towards the side of their lesion (Azouvi et al., 2002; Barton, Behrmann, & Black, 1998). In contrast, a number of studies have shown that patients with isolated homonymous hemianopia and no neglect show a systematic bisection error in the contra-lesional direction, towards their blind side (Barton et al., 1998; Barton & Black, 1998; Doricchi, Onida, & Guariglia, 2002; Hausmann, Waldie, Allison, & Corballis, 2003; Kerkhoff, 1993; Zihl, Samann, Schenk, Schuett, & Dauner, 2009), a bias first reported over 100 years ago (Axenfeld, 1894; Kerkhoff & Bucher, 2008; Liepmann & Kalmus, 1900).

Several possible explanations for hemianopic bisection error have been advanced (Barton & Black, 1998; Kerkhoff & Bucher, 2008). One is that it is a direct consequence of the field loss: when healthy subjects bisect lines extending from their fovea into the visual periphery in one hemifield, they err towards fixation, the equivalent of a bias towards a blind field (Nielsen, Intriligator, & Barton, 1999). A second possibility is it reflects long-term strategic adaptation to hemianopia (Barton & Black, 1998; Doricchi et al., 2002; Machner, Sprenger, Hansen, Heide, & Helmchen, 2009): during visual search, hemianopic patients show a gradient of increasing fixations towards their blind side (Behrmann, Watt, Black, & Barton, 1997), suggesting a compensatory increase in the exploration of contra-lesional space after hemianopia. A third possibility that has been advanced is that contra-lesional bisection bias is due not to hemianopia, but to damage to extrastriate regions adjacent to the optic radiations or striate cortex (Zihl et al., 2009).

To investigate this further, a recent study of healthy subjects used a simulated hemianopia created by a gaze-contingent display, a strategy used previously to study gaze adaptation to such field defects (Zangemeister & Utz, 2002). This found that the simulation induced either no bias or even a small ipsilateral bisection error (Schuett, Kentridge, Zihl, & Heywood, 2009). While this does not exclude the possibility that strategic adaptation over time could lead to a contra-lesional bisection error, such a result would argue that contra-lesional bisection error is not a direct consequence of field loss.

To verify such an important finding we performed another study, first to replicate the results and second to examine the impact of a number of methodological factors that could affect the results. First, the longest line used in this study was 16° (Schuett et al., 2009), whereas most studies of bisection error in real hemianopia used longer lines (Barton & Black, 1998; Ishiai, Furukawa, & Tsukagoshi, 1989; Zihl et al., 2009). Line-length has an impact on bisection error in hemineglect (Marshall & Halligan, 1989), and

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one of the earliest reports also claimed that hemianopic bias in bisection disappeared if lines were too short or too long (Kerkhoff & Bucher, 2008; Liepmann & Kalmus, 1900). Indeed, Schuett et al. (2009) raised the possibility that line-length could account for their difficulty in replicating hemianopic bisection error. Second, all line stimuli used in this study had their center aligned with the center of the monitor and the mid-sagittal plane of the subjects, without variation. Predictability and the centering of these lines may have afforded subjects extraneous cues to the location of line center, countering any systematic error based on visual information alone. Third, the simulation of homonymous hemianopia spared 1° of visual field along the vertical meridian. As there is some evidence that sparing of the central field may reduce contra-lesional bisection bias in hemianopia (Barton & Black, 1998) – but see (Zihl et al., 2009) for a contrasting result – this may have reduced the ability of this study to find bias. Last, the lines used in this study did not have their ends marked, unlike the lines used in some prior studies of hemianopic bisection error (Barton & Black, 1998). Without such markers, a hemianopic subject would not know on any given fixation whether they were viewing the entire line or merely a portion of it. Bisection judgments that fail to incorporate the entire contra-lesional extent of the line would be biased ipsilaterally, potentially masking any contra-lesional bias.

Our goal then was to determine if, after considering these factors, subjects with a simulated hemianopia would show a contra-lesional bisection error, similar to that seen in real hemianopia. If so, this would imply that the consequences of hemianopia for visual search are sufficient to cause contra-lesional bisection error. If not, this would imply that either chronic adaptation or additional extrastriate deficits are required for its manifestation.

1. Experiment 1

1.1. Methods

1.1.1. Participants

10 subjects with median age 27 (range 23–37) participated in the experiment. For this and the second experiment, all participants had corrected visual acuity of 20/20 and no history of neurological disease. All were naïve to the purpose of the experiment. We included only right-handed participants with a laterality quotient of more than +70 on the Edinburgh Handedness Inventory (Oldfield, 1971), to minimize variability from effects of handedness on line bisection (Brodie & Pettigrew, 1996). All subjects gave informed consent in accordance with the principles of the Declaration of Helsinki and the Institutional Review Boards of the University of British Columbia and Vancouver Coastal Health approved the protocol.

1.1.2. Apparatus

An NEC FE2111SB monitor (140 Hz, 22 in., 1024 × 768 pixels) was used to display the experiment at a viewing distance of 34 cm from the cornea, with a refresh rate of 140 Hz. The screen subtended 60° horizontally and 48° vertically. We used an Eyelink 1000 video-based eye tracking system (www.sr-research.com) to record the position of the left eye during binocular viewing, at a sampling rate of 1000 Hz.

1.1.3. Stimuli

We used black lines of four lengths; short (8° of visual angle in length, 0.30° thick), medium (12° long, 0.45° thick), long (16° long, 0.60° thick), and very long (34° long, 1.28° thick), shown on a white background. The lengths of the short, medium, and long lines matched the line-lengths used in the prior study of simulated hemianopia (Schuett et al., 2009), while that of the very long line matched that used in a study of true hemianopia (Barton et al., 1998). Although the lines used in the prior simulated hemianopia study were all 0.45° thick (Schuett et al., 2009), we matched this only for the medium line, varying thickness for the others in proportion to their length, to create approximately equivalent visibility of the ends of the lines in the far periphery, particularly for the very long line, since spatial resolution is limited in the peripheral visual field (Anderson, Mullen, & Hess, 1991). For stimuli with marked ends, lines terminated at both ends in a short vertical line whose width was the same as that of the line and whose height was three times its width. By using markers at both line ends and not just one, we avoided issues that unilateral markers can create a false appearance of extending the line on one side, which might alter the 'point of balance' (Mattingley, Pierson, Bradshaw, Phillips, & Bradshaw, 1993; Olk & Harvey, 2002). In full viewing by normal subjects and patients with hemineglect, bilateral markers at line ends do not induce a bisection bias (Olk & Harvey, 2002).

All lines were centered vertically on the screen; however, horizontal position was varied, with lines centered at three different positions: screen midline, 3° left, or 3° right of midline. Each line was presented in each position four times in a block. This variation was used to minimize extraneous cues to line center.

1.1.4. Procedure

The eye tracker was calibrated using a nine-point grid spanning 30° right and 30° left of center before each recording session. Drift error was assessed before each trial and the system was recalibrated with the nine-point grid if the error exceeded 1°. Participants rested their heads against the system's tower mount, which had both a head rest and a chin rest. The subject's mid-sagittal plane was centered with respect to the computer monitor. Bright ambient room illumination was kept constant throughout the experiment for all subjects. The programming of the experiment was done in Experiment Builder 1.5.1 (www.sr-research.com).

A gaze-contingent display paradigm was used to simulate complete left- and right-sided homonymous hemianopia (LHH, RHH) in healthy participants. During hemianopic conditions the entire screen to the left (LHH) or right (RHH) of the current point of fixation was set to the same luminance and colour of the background. Screen updates occurred within a single frame (maximum lag of 7 ms). If the subject's gaze was directed outside of the monitor or if the eye tracker lost track of the pupil, as could occur if the subject pulled their head away from the eye tracker or closed their eyes, the entire screen assumed the colour of the background.

Each trial started with a fixation cross. The bisection task only began when gaze was within 0.5° of the center of this cross for 200 ms. If this criterion was not met within 4 s, calibration was reassessed. Subjects were instructed to perform the bisection by moving a mouse-controlled cursor, which was a triangle with a base and height of 1.28°. They were to click the mouse when the tip of the triangle was located at the point that they perceived to be the midpoint of the line. The cursor started each trial at the bottom of the screen, half the time it was 3° left and half the time it was 3° right of the vertical midline of the computer monitor. Subjects were instructed to be as accurate as possible and told that there were no time restrictions. Clicking any mouse button finalized the bisection and initiated the next trial, which started after 500 ms. Participants received no feedback on bisection accuracy, to avoid practice effects.

The experiment consisted of two parts. The first part presented end-marked lines and the second part presented unmarked lines. Half the subjects bisected end-marked lines first and half bisected unmarked lines first. Each part consisted of three blocks, with two possible orders. In one, subjects experienced LHH in the first block, RHH in the second block, and finally full viewing in the last block. In the second, subjects experience RHH first, LHH second, and full viewing third. Each block consisted of 48 line bisection trials, 12 of each of the four different line-lengths in random order, with screen position also randomized.

1.1.5. Analysis

For bisection performance we calculated the deviation of the cursor position from the objective line center for each trial, with negative values indicating a leftward bias and positive values a rightward one. This was then divided by the total line-length to give a percent bisection error. (To provide a view of absolute bisection effects as well, our figures show bisection error in degrees of visual angle.) Percent bisection error was subjected to ANOVA with main factors of viewing condition (LHH, RHH and full viewing), line-length (short, medium, long and very long), and end-type (unmarked or end-marked), with subjects as a random factor, using JMP 8.0.2 (www.jmp.com). Interactions were investigated with Tukey's honestly significant difference (HSD) test and *a priori* comparisons quantified with linear contrasts. We also measured bisection time, which was the interval between stimulus onset and the time of the mouse click, and subjected this to a similar ANOVA.

For ocular motor search strategy, our main outcome measure was the median value of the horizontal position of eye fixations, which we again expressed as a percent of line-length. We also assessed indices of visual search that have been used in prior studies (Barton et al., 1998; Schuett et al., 2009). Other ocular motor parameters that may indirectly reflect bisection performance include the longest fixation and the final fixation at the moment when the subject is marking their bisection point. These were again statistically analyzed as a percentage of line-length. Right- and leftmost fixations were measured as indices of the span of visual search: these were expressed in degrees of visual angle rather than percent of line-length, because our interest was in how much of the display screen was viewed in each condition. All parameters were analyzed with ANOVA with the main factors of viewing condition (LHH, RHH and N), line-length (short, medium, long, and very long), and end-type (unmarked and end-marked), with subjects as the random factor.

In addition to these indices, for illustrative and comparative purposes we plotted fixation density, similar to that done in a prior report on true hemianopia (Barton et al., 1998). We first normalized the horizontal position of fixations as a fraction of line-length, and then, using all fixations for all subjects and for all line-lengths, we sorted fixations by their normalized horizontal position. For each fixation we calculated the average distance between the 40 adjacent fixations (20 on each side): the inverse of this average, divided by 100 and then by the number of lines (4), represents fixation density, expressed as number of fixations made by the group per percent of line-length.