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ORIGINAL ARTICLE

Left of centre: asymmetries for the horizontal vertical line illusion

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Abstract This study explored the mechanisms that underlie asymmetries for the horizontal vertical illusion (HVI), which deceives length perception, so that a vertical line is perceived as longer than a horizontal line of equivalent length. In Experiment 1, university students ($n = 14$) made length judgements for vertical and horizontal lines. The vertical line was shifted in eight steps from the far left of the horizontal line (⌊) to the far right (⌋). An HVI was observed for the medial positions (⊥), which diminished towards the lateral positions. The HVI was also stronger when the vertical line was on the left. Because the left/right asymmetry changed as a function of lateral/medial position, the asymmetry within the HVI stimulus is most likely the result of pseudoneglect, which affects judgements of horizontal length. In Experiment 2, participants ($n = 15$) made judgements for HVI stimuli presented to the left- and right-hemispace and the midline. The HVI was stronger in the left hemispace. Because the asymmetry between the left- and right-hemispaces did not interact with the asymmetry within the stimuli, it was concluded that the asymmetry between hemispatial positions was the result of right hemisphere susceptibility to illusory geometrical effects whereas the asymmetry within the stimulus is related to an object-centred attentional asymmetry. The HVI is affected by asymmetries in length judgements and susceptibility to illusions and may provide interesting insights into attentional disorders in clinical populations, such as neglect.

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Introduction

Geometric visual illusions can dramatically distort our perception, leading us to misjudge the size, position and length of lines or shapes in a visual scene (Gregory, 1998). Besides being intrinsically interesting, geometric illusions also provide a valuable insight into the cognitive and neural mechanisms that underlie perception because the physical properties of stimuli can be dissociated from their perceptual effects.

Illusions of length have been used to explore asymmetries in the neural and cognitive mechanisms that control spatial attention. For example, the Müller-Lyer illusion has proved useful in the study of spatial neglect following damage to the right parietal cortex. While the ability of neglect patients to perceive and bisect lines is severely impaired, the majority of the research shows that the illusory effect of the Müller-Lyer figure is preserved (Daini, Angelelli, Antonucci, Cappa, & Vallar, 2002; Mattingley, Bradshaw, & Bradshaw, 1995; Ro & Rafal, 1996). This dissociation in performance is supported by fMRI research, which demonstrates that distinct neural structures are associated with performance on line bisection and Müller-Lyer stimuli (Weidner & Fink, 2007). In addition to bilateral activation of the lateral occipital cortex, the Müller-Lyer illusion caused activation of the right superior parietal cortex and the right intraparietal cortex. A right hemisphere locus for the Müller-Lyer illusion is further supported by divided visual field research. Clem and Pollack (1975) presented Müller-Lyer figures to the left and right visual fields and found a larger illusion when the figure was presented simultaneously to the left visual field/right hemisphere.

Besides the Müller-Lyer illusion, illusions of length can also be induced using the horizontal vertical illusion (HVI). The HVI works to deceive our perception of line length, so that a vertical line is perceived as longer than a horizontal line of equivalent length (Kunnapas, 1955; Finger & Spelt, 1947). The effect is maximised when the vertical line is placed in the middle of the horizontal line (i.e. ⊥) and minimised when the vertical line appears at either end of the horizontal line (i.e. ⌊ or ⌋) (Charras & Lupiáñez, 2010; Kunnapas, 1955; Wolfe, Maloney, & Tam, 2005).

Charras and Lupiáñez (2010) have proposed that two mechanisms contribute to the HVI. The first is a 'vertical bias' whereby vertical lines appear longer than horizontal lines of a similar length. The vertical bias could be the result of depth cues related to the perception that the vertical line recedes in space (Yang, Dixon, & Profitt, 1999) or intrinsic properties of the visual system related to the shape of the visual field (Prinzmetal & Gettleman, 1993). The other mechanism is related to a 'bisection bias'. In this case, lines that are bisected are perceived to be longer than those that are not. Charras and Lupiáñez (2009) have demonstrated that the degree to which the length of the bisected line is overestimated is related to the symmetry of the bisection. As a result, overestimation for lines that are bisected symmetrically is relatively small and increases with the asymmetry of the bisection.

It appears the vertical and bisection biases interact in an additive manner when producing the HVI. In their first experiment, Charras and Lupiáñez (2010) presented HVI stimuli where the vertical line was located at either end of the horizontal line (⌊ or ⌋), in the middle (⊥) and at two intermediate position to the left and right of centre. The HVI was strongest when the vertical line was in the centre, or at either end,—but was substantially reduced for the intermediate positions. Charras and Lupiáñez (2010) suggested that the vertical bias accentuated the length of the vertical line in the centre and the end conditions. For the intermediate positions, however, the asymmetrical bisections accentuated the length of the horizontal line. Because the length of the horizontal line is accentuated, it overcame the vertical bias, resulting in no overall bias in either direction (see also; Expt. 1 in Wolfe, Maloney, & Tam, 2005 and Charras & Lupiáñez (2009)).

Charras and Lupiáñez (2010) presented the vertical lines to the left and right of the horizontal line, but collapsed across this factor in their analyses. They did this: "To control for asymmetrical differences in spatial attention" (p. 198). It is possible, however, that left/right asymmetries may provide an important insight into the nature of the bisection bias. Asymmetries in line bisection are well known in clinical and non-clinical populations. While patients with right parietal damage and neglect bisect lines far to the right of their true centre (Heilman, Watson, & Valenstein, 1993), the general population shows a subtle effect in the opposite direction—known as pseudoneglect (Jewell & McCourt, 2000). Pseudoneglect is a reliable phenomenon (McCourt, 2001) and is most likely caused by a bias of attention to the left side of peripersonal space (Nicholls & Roberts, 2002). Pseudoneglect appears to share much in common with clinical neglect and both are affected by a similar set of stimulus variables (e.g. Loftus, Vijayakumar, & Nicholls 2009; McCourt & Jewell, 1999) and have a similar neural basis (Bjoertomt, Cowey, & Walsh, 2002; Foxe, McCourt, & Javitt, 2003; Waberski, Gobbelé, Lamberty, Buchner, Marshall, & Fink, 2008). While pseudoneglect shifts line bisections to the left, it also appears to affect judgments of length. Charles, Sahraie, and McGeorge (2007) presented participants with ellipses that varied in their vertical and horizontal dimensions to the left and right hemispace. For horizontal judgements, an asymmetry was observed whereby ellipses presented to the left were judged to be longer compared to those presented on the right. For judgments of vertical length, no asymmetry was observed.

Although no study has explicitly sought to investigate asymmetries in hemispheric function and attention using the HVI, Wolfe, Maloney, and Tam (2005) observed an asymmetry as an aside of research examining the effect of perspective on the HVI. They presented various two-line configurations of the illusion to participants, whereby the vertical line was laterally shifted to 11 intermediate positions along the horizontal line. They reported that the magnitude of the illusion systematically diminished as the position of the vertical line shifted from its central location (⊥) towards either end (⌊ or ⌋) (like Charras & Lupiáñez, 2010). Critically for the current study, the strength of the illusion was stronger when the vertical line was to the left of centre.

Wolfe and colleagues suggested that the left/right asymmetry "might reflect the dominance of the right hemisphere in illusion perception" (Wolfe et al., 2005, p. 972). Whether or not the right hemisphere is more prone to illusory effects is the subject of debate. For example, Rasmjou, Hausmann, and Güntürkün (1999) reported a stronger Herringbone illusion for the right hemisphere—but only for males. Rothwell and Zaidel (1990) also observed a stronger Oppel-Kundt illusion for left visual field/right hemisphere trials—but only for simultaneous presentations. In contrast, Grabowska, Szymanska, Nowickam, and Kwiecien (1992) found that left- and right-hemisphere lesions did not differentially affect susceptibility to the Ponzo, Ehrenstein-Orbison, Poggendorff and Zoellner illusions. When suggesting a right hemisphere locus for illusions, it is also important to bear in mind that visual illusions encompass a wide range of dimensions, including; geometry, brightness, colour and motion. It is, therefore, unlikely that a single (right hemisphere) mechanism can modulate their strength. Besides inconsistencies in the research, it is also unclear how the stimuli used by Wolfe et al. (2005) led to a perceptual asymmetry. Although the position of the vertical line was shifted to the left or right, the position of the whole stimulus remained in the centre of the screen. The stimulus itself was relatively small (2.7° visual angle) and the vertical line shifted in increments of 0.27° of viewing angle. It is unlikely that this procedure would induce a perceptual asymmetry, given that stimuli usually need to be shifted by 1–2° to the left or right hemispaces or visual fields (Lindell & Nicholls, 2003).

Instead of reflecting lateralisation for illusions, the left/right asymmetry observed by Wolfe et al. (2005) may be related to pseudoneglect, which affects the estimation of line length. This effect of pseudoneglect is most likely limited to length estimation for horizontal lines, but not for vertical lines (Charles et al., 2007). If it is assumed that the vertical line attracts attention and defines the stimulus (see, Charras & Lupiáñez, 2009), the following predictions can be made. For a line of length L, the portion that falls to the left or right of the vertical line is termed l or r, respectively. Estimates of the length for l and r will be modified by the effect of pseudoneglect (pn). In the case of the portion of the line falling to the left, pn will increase the perceived length whereas the portion of the line falling to the right will be reduced by pn. The overall estimation of length can, therefore, be described by the following equation: *Horizontal length* $= ((l + (l \times pn)) + ((r - (r \times pn))$. It can be seen that, for trials where the vertical line is shifted to the left, more of the horizontal line falls to the right—resulting in a lower estimate of the overall length of the horizontal line. If the horizontal line is judged to be shorter, it would result in a larger HVI. The opposite would apply for trials where the vertical line is shifted to the right. While this model predicts a larger HVI when the vertical line is shifted to the left, it also predicts that the asymmetry should increase as the lines move from the medial to the lateral locations.

The HVI is an interesting phenomenon and has the potential to provide insights into how line length is estimated and the effect of attention. With this in mind, the current study sought to clarify the nature of the asymmetry for the HVI and explore the mechanisms that give rise to the illusion.

Experiment 1

Participants made judgements of relative length for horizontal and vertical lines. To examine asymmetries in the HVI, the position of the vertical line was shifted in eight steps from the far left of the horizontal line to the far right. Previous studies investigating the HVI have often employed a method-of-adjustment procedure where participants manually alter the length of the vertical line until it reaches a point of subjective equality with the horizontal line (Finger & Spelt, 1947; Kubi & Slotnick, 1993; Prinzmetal & Gettleman, 1993; Richter, Wennberg, & Raudsepp, 2007). While this method is suitable for perceptual research, it is not so suited to studies of attention because it requires systematic visual scanning and the use of gross motor movements (see Jewell & McCourt, 2000). To avoid such effects, the current study employed a forced-choice procedure with a bimanual response (see; Charras & Lupiáñez, 2010; Wolfe et al., 2005).

In keeping with previous research, it was expected that the HVI would be maximised when the vertical line was placed near the middle of the horizontal line (Wolfe et al., 2005). The HVI was then expected to diminish as the vertical line moved towards the lateral positions (Charras & Lupiáñez, 2010; Kunnapas, 1955; Wolfe et al., 2005). If the left/right asymmetry observed by Wolfe et al. (2005) is a reliable effect, the HVI should be larger when the vertical line is placed to the left compared to the right. Finally, if the left/right asymmetry for the HVI is related to separate estimates of the length of horizontal line to the left and right of the vertical line, the asymmetry should increase as the vertical line moves from the medial to the lateral positions.

Method

Participants

Fourteen first-year psychology students (f = 13, m = 1) participated as part of their course requirement. All were right-handed ($M = 80.2$, $SD = 19.17$) as determined by the Edinburgh Inventory (Oldfield, 1971). Participants were aged between 17 and 20 years ($M = 18.07$, $SD = 0.73$). All had normal or corrected-to-normal vision and were naïve about the purpose of the experiment, although prior informed consent was obtained. The study had approval from the Melbourne University Human Research Ethics Committee.

Apparatus

Stimulus presentation was controlled via a PC with digital input/output card and on-board millisecond timer (Blue Chip Technology, DCM-16). Stimuli were presented on a 365 × 275 mm CRT monitor, with a spatial resolution of 640 × 480 pixels and refresh rate of 16.8 ms. A height-adjustable chin rest maintained participants' head position so that the centre of the monitor was in line with their mid-sagittal plane at eye level. A four-button response panel, which also lay in parallel with participant's mid-sagittal plane, was used to record bimanual responses. A closed-circuit video camera ensured that participants' concentration was maintained during the experiment.

Stimuli

The two line segments, one horizontal and one vertical, were white against a black background. The thickness of the lines was 0.13° (2 pixels). The length of the horizontal line remained constant at 5.26°, whereas the length of the vertical line varied so that it was shorter than the horizontal line for half of the trials, and longer for the other half. Difficulty of length judgment was varied so that the vertical line was either two or four pixels longer or shorter than the horizontal line (5.26° ± 0.13°, or 5.26° ± 0.26°).

The horizontal line was always presented in the centre of screen. The vertical line was positioned so that its bottom edge touched the bottom edge of the horizontal line. The location of the vertical line along the horizontal line was varied in eight steps from the far left to the far right (see top of Figs. 1, 2). Note that the vertical line never appeared in the exact middle of the horizontal line.

Procedure

There were 32 stimulus configurations, which comprised the conditions of length of the vertical line relative to the horizontal line (0.13° shorter, 0.26° shorter, 0.13° longer or 0.26° longer), side on which the vertical line appeared (left or right) and position of the vertical line on the left or right sides [1 (medial), 2, 3 or 4 (lateral)]. Participants judged each of these 32 conditions 16 times, resulting in 512 trials, which were broken into four equal blocks. Within each block, a representative proportion of the different configurations occurred and the order in which they occurred was randomised.

Participants sat 500 mm from the computer monitor and were told that for each stimulus displayed on the screen, the vertical line position would vary in relation to the horizontal line, while the horizontal line would remain in a constant position. On each trial, participants indicated whether they perceived the vertical or horizontal line to be longer. To avoid any confusion, participants were asked to judge the length of each line from one extreme end to the other. Participants pressed the two upper buttons with the middle fingers of both hands if they perceived the vertical line as longer, and the two lower panel buttons with their index fingers if they perceived the horizontal line as longer. They were asked to concentrate carefully on the stimuli and aim for accuracy. Although reaction time was irrelevant to the task, they were reminded that a prompt response was required within 4 s of the stimulus being removed from the screen. The trial was automatically rejected and replaced if a response was made before the stimulus had left the screen, or after the allotted four-second response interval.

Participants performed a practice block of 32 trials before the experimental task was performed. Each trial began with a small fixation cross (1.37° across) centred on the screen. The cross was presented for 500 ms, followed by a blank screen for 500 ms. The stimulus then appeared in the centre of the screen for 672 ms. This was followed by a blank screen until the observer responded. The next trial followed 1,500 ms after the participant's response.

Results and discussion

A measure of percent error was calculated by identifying trials where the short and long vertical line was identified correctly. The mean overall error rate was 27.16% ($SD = 5.88$), with individual mean scores ranging between 19.53 and 42.19%.

To obtain a measure of response bias, the data were collapsed across the four different lengths of the vertical line. The number of trials where the horizontal line was judged to be longer was then subtracted from the number of trials where the vertical line was judged as longer. This value was divided by the number of trials in each condition (16) and converted to a percentage. A positive bias indicates that the vertical line was perceived to be longer (the HVI), whereas a negative bias indicates that the participant thought the horizontal line was longer. A value of 0% indicates no bias.

An ANOVA was used to analyse response bias with position (1, 2, 3, 4) and side (left, right) as within-participants factors. Effect sizes are expressed as partial eta-squared values. A significant effect of position was found [$F(3, 39) = 41.39$, $p < 0.001$, $\eta_p^2 = 0.761$]. Figure 1 illustrates the effect of position whereby an illusion for the medial locations declined towards the lateral positions, resulting in significant linear [$F(1, 13) = 43.473$, $p < 0.001$, $\eta_p^2 = 0.77$] and quadratic [$F(1, 13) = 43.438$, $p < 0.001$, $\eta_p^2 = 0.77$] effects. To test whether the biases were significantly different from zero for each of the eight conditions, a series of one-sample t tests were conducted. To control for multiple comparisons, the critical p was Bonferroni adjusted to 0.006. As can be seen in Fig. 1, there was a significant HVI for position L1 whereas the illusion just failed to reach statistical significance for position R1 ($p = 0.008$). There was a significant bias toward selecting the horizontal line as longer for positions R3 and R4 (i.e. a 'reverse' HVI).

The presence of the HVI for the medial condition and the decline for the lateral conditions replicates the results of previous research (Charras & Lupiáñez, 2010; Kunnapas, 1955; Wolfe et al., 2005, Expt. 1). The decline in the HVI towards the lateral positions may reflect the operation of the 'bisection bias' proposed by Charras and Lupiáñez (2010), which increases as the bisection becomes more asymmetrical. It is surprising, however, that the HVI decreased to such an extent in the lateral positions that a reversed HVI

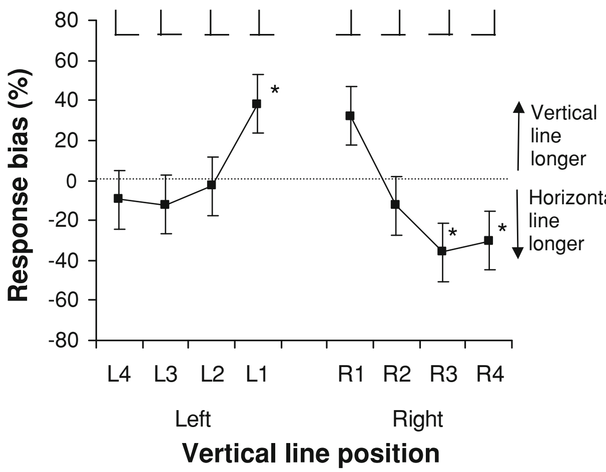

Fig. 1 Mean response bias (±95% confidence intervals, Loftus & Masson (1994)) for the different vertical line positions. An *asterisk* (*) indicates the positions where the bias was significantly different from zero for $p < 0.006$ (Bonferroni adjusted for multiple comparisons). The different vertical line positions are shown at the *top* of the graph

was observed. Thus, for positions 3 and 4 on the right side, participants perceived the horizontal line to be longer. It is interesting to note that two out of seven of the participants used by Wolfe et al. (2005) also showed a reversed HVI in these conditions. A number of processes may be operating to produce this effect. First, the reversed HVI may reflect a contextual effect, which is known to play an important role in the HVI (Armstrong & Marks, 1997). In the case of a medial presentation, the vertical line appears clearly longer due to the vertical bias. If this trial is followed by a lateral presentation, the vertical line will look markedly shorter than the previous trial—resulting in a bias towards horizontal responses. Alternatively, the reversed HVI could reflect a misunderstanding on behalf of the participants. Participants were explicitly instructed to judge the lines from their extremes. It is possible, however, that participants judged the length of the vertical line from the upper edge of the horizontal line rather than the bottom edge. As a result, the length of the vertical line is always judged to be 2 pixels (0.13°) shorter than it should be. This shortening would apply to all eight positions of the vertical line and would result in a downwards shift (see Fig. 1) for all the data. This shift would cause a general reduction of the HVI, resulting in a reversed HVI in the right lateral conditions.

Figure 1 shows there was an effect of side on response bias [$F(1, 13) = 25.34$, $p < 0.001$, $\eta_p^2 = 0.661$], where response bias on the left ($M = 3.43$, $SD = 29.71$) was shifted towards the illusion, whereas the bias on the right ($M = -11.75$, $SD = 25.81$) was shifted away from the illusion. The effect of side is in accordance with Wolfe and colleagues' (2005) report of a stronger HVI when the vertical line was placed to the left. If this asymmetry is the product of pseudoneglect for the horizontal line, the asymmetry should increase as the vertical line moves from the medial to the lateral positions. In partial support of this hypothesis, the interaction between side and position approached, but did not reach statistical significance [$F(3, 39) = 2.11$, $p = 0.11$, $\eta_p^2 = 0.14$]. Despite the lack of a significant interaction effect, and because of the theoretical importance of this interaction, a set of four Bonferroni-adjusted post-hoc comparisons were performed. The asymmetry was significant at positions 3 [$t(13) = 4.68$, $p < 0.001$] and 4 [$t(13) = 2.65$, $p = 0.01$] only. It should be acknowledged, however, that the interaction between side and position was not significant and that, strictly speaking, post-hoc tests should not be carried out. Power analyses revealed that a strong effect (≥0.8 according to Cohen (1988) criteria) should have been detected with a sample size of 16. It is therefore possible that a significant effect would have been observed if more participants were tested.

The data collected in this experiment replicate the left/right asymmetry reported by Wolfe et al. (2005). In addition, we have demonstrated an asymmetry for the HVI, but only for the lateral positions. Stronger asymmetries in the lateral conditions could be because the relative proportions of the horizontal line falling to the left or right of the vertical line is less balanced—leading to larger differences in estimation of line length. In addition to supporting Charras and Lupiáñez's (2010) proposition that bisection biases play an important role in the HVI, the present data demonstrate that the bisection bias is also affected by well-known left/right asymmetries in attention.

Experiment 2

While experiment 1 manipulated asymmetries *within* the stimulus, Experiment 2 explored asymmetries within and between stimuli. To this end, the HVI stimuli were presented to the left- and right-hemispaces and along the midline.

The midline condition replicated the conditions used in Experiment 1 and the same basic effects were expected. For the left- and right-hemispace conditions, a number of predictions were made. Studies with clinical neglect patients demonstrate that attention within and between objects both play an important role in the manifestation of neglect symptoms (Ota, Fujii, Suzuki, Fukatsu, & Yamadori, 2001; Tipper & Behrmann, 1996). Similarly, for normal participants, attentional asymmetries within and between the objects both play a role in pseudoneglect (Nicholls, Hughes, Mattingley, & Bradshaw, 2004; Post, Caufield & Welch, 2001). If the left/right asymmetry observed in Experiment 1 is based on an attentional asymmetry within an object, the asymmetry should be the same irrespective of where the stimulus occurs. Within this model, it is also possible that centrifugal forces affect line bisection as it moves away from the centre (McCourt, Garlinghouse, & Slater, 2000). While this centrifugal effect may affect the degree of asymmetry for the lateral presentations relative to the midline, importantly, it would not result in an asymmetry between the left and right conditions.

Alternatively, asymmetries between objects and spatial locations may play a role. A number of researchers have demonstrated that the leftward misbisections caused by pseudoneglect are stronger for lines presented in the left hemispace compared to the right hemispace (McCourt & Jewell, 1999; Reuter-Lorenz, Kinsbourne, & Moscovitch, 1990). If the misrepresentation of the left and right sides of the bisection are more pronounced on the left side, one would predict a stronger left/right asymmetry for left hemispace presentations compared to right hemispace presentations (i.e. an interaction between hemispace and the side on which the vertical line appeared within the stimulus).

Finally, it is possible that moving the stimuli into the left and right hemispace will make them susceptible the hemispheric asymmetries in geometric illusions. Although the literature is not conclusive, there is some suggestion that the right hemisphere is more prone to geometric visual illusions (Clem & Pollack, 1975; Rasmjou et al., 1999; Rothwell & Zaidel, 1990). If this is the case, the HVI should be stronger for presentations to the left hemispace compared to the right hemispace.

Method

Participants

Fifteen first-year psychology students (f = 11, m = 4) participated in the experiment. All were right-handed ($M = 88.13$, $SD = 15.44$) and were aged between 18 and 21 years ($M = 18.67$, $SD = 0.98$). All other characteristics were the same as Experiment 1.

Stimuli and procedure

The methodology was the same as Experiment 1 except for the inclusion of hemispace as a new factor. The HVI stimuli were presented at random to either the left- or right-hemispaces or along the midline. For the left and right hemispatial stimuli, the inner-edge of the stimulus was displaced by 6.86° from the left or right of the midline of the monitor. The addition of hemispace (left, midline and right) increased the number of factorial combinations from 32 to 96. Participants completed 480 trials broken into five blocks of 96 trials. The order in which the trials occurred was randomised within each block. A practice block of 96 trials was performed prior to the experimental task. All other details of the apparatus, experimental design and procedure were identical to that of Experiment 1.

Results and discussion

Percent error was calculated as described in Experiment 1. The mean overall error rate was 27.40% ($SD = 6.96$), ranging between individuals from 13.75 to 42.5%.

Response bias data were analysed with an ANOVA with position (1, 2, 3, 4), side (left, right) and hemispace (left, midline, right) as within-participant factors. A significant main effect of position was found [$F(3, 42) = 26.20$, $p < 0.001$, $\eta_p^2 = 0.652$], with contrasts revealing a significant linear [$F(1, 14) = 41.75$, $p < 0.001$, $\eta_p^2 = 0.759$] and quadratic effect [$F(1, 14) = 19.91$, $p = 0.001$, $\eta_p^2 = 0.587$] (see Fig. 2). A strong HVI for the medial positions, which diminished towards the lateral positions, replicates the results observed in Experiment 1 and by other researchers (Charras & Lupiáñez, 2010; Kunnapas, 1955; Wolfe et al., 2005). A series of one-sample *t* tests determined the positions at which response bias was significantly different from zero. To control for multiple comparisons, the critical *p* was Bonferroni adjusted to .002 (see Fig. 2 for results). A significant HVI was observed for conditions at L1 and R1. A reversed HVI was observed for conditions at positions R3 and R4. These significant biases closely approximate the results reported for Experiment 1.

There was a main effect of side [$F(1, 14) = 14.05$, $p < 0.05$, $\eta_p^2 = 0.501$], whereby the HVI was present when the vertical line was on the left, but reversed when the vertical line was on the right. The direction of this effect is the same as Experiment 1 and replicates the asymmetry observed by Wolfe et al. (2005). Like Experiment 1, the interaction between side and position failed to reach statistical significance [$F(3, 42) = 1.56$, $p = 0.21$, $\eta_p^2 = 0.101$]. For the sake of comparison with Experiment 1, however, post-hoc *t* tests were carried out (Bonferroni corrected). The mean asymmetry for positions 1–4 was 4.0, 13.1, 16.7 and 20.7, respectively. The asymmetry was significant for positions 2, 3 and 4 (all ps < 0.025), but not for position 1. Although the effect is weak, the interaction between side and position is similar to that observed in Experiment 1. Like Experiment 1, it is possible that a significant interaction would have been observed if the sample size was increased. The effect of side and position supports Charras and Lupiáñez's (2010) suggestion that the bisection bias plays an important role in the extent of the HVI. In addition, asymmetries in the perceived length of the left and right segments affect the relative strength of the bisection bias.

An effect of hemispace was observed [$F(2, 28) = 35.36$, $p < 0.001$, $\eta_p^2 = 0.716$]. Contrasts revealed that the HVI was strongest in the left hemispace compared to the midline

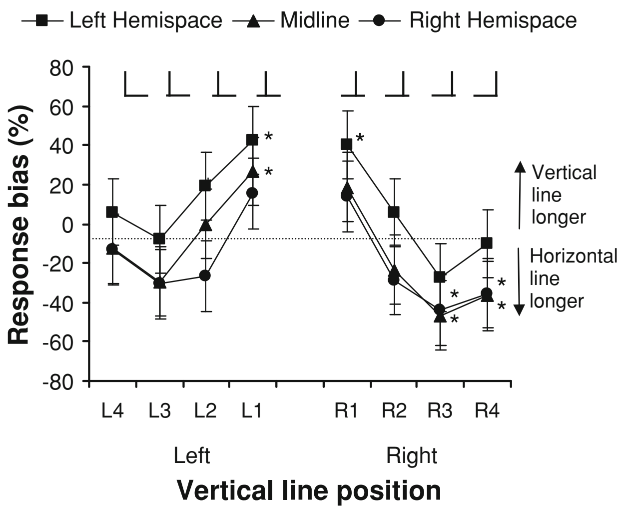

Fig. 2 Mean response bias (±95% confidence intervals) for the different vertical line positions across the hemispaces. An *asterisk* (*) indicates the positions where the bias was significantly different from zero for $p < 0.002$ (Bonferroni adjusted for multiple comparisons). The different vertical line positions are shown at the *top* of the graph

[$t\,(14) = 6.91$, $p < 0.001$] and right hemispace [$t\,(14) = 6.61$, $p < 0.001$] conditions. There was no difference between the midline and right hemisphere conditions ($t\,(14) = 2.0$, ns]. Thus, while there is a strong difference between the left- and right-hemispaces, only the left hemispace showed a difference relative to the midline (baseline) condition. Differences in the degree of asymmetry from the baseline are common within the perceptual literature (Loftus, Nicholls, Mattingley, & Bradshaw, 2008; Nicholls & Roberts, 2002) and may reflect floor or ceiling effects for the behaviour or the pattern of hemispheric dominance when viewing is not lateralised. The asymmetry between the hemispaces may reflect a greater sensitivity to illusory effects in the right hemisphere (see, Clem & Pollack, 1975; Rasmjou et al., 1999; Rothwell & Zaidel, 1990). As a result, the HVI was stronger overall for left hemispace conditions, because that side of space is preferentially processed by the right hemisphere (Corbetta, Miezin, Shulman, & Petersen, 1993).

The effect of hemispace was moderated by an interaction with position [$F\,(6,\ 84) = 2.46$, $p < 0.05$, $\eta_p^2 = 0.150$]. Inspection of Fig. 2 reveals that the lines for the different hemispatial conditions run nearly parallel to one another for all positions except for one point at position L2. At this position, the reversed HVI for right hemispace presentations was significantly stronger compared to midline presentations [$t\,(14) = 4.28$, $p < 0.005$). There is no obvious explanation for this interaction.

Critically, for the present study, there was no interaction between hemispace and side [$F\,(2,\ 28) = 1.13$, ns]. If pseudoneglect was stronger for presentations in the left hemispace compared to the right (i.e. a between objects asymmetry), the left/right asymmetry should have been stronger for left hemispace presentations. Instead, the data show that the left/right asymmetry within the HVI stimulus was constant irrespective of where it fell. This lends support to the theory that the left/right asymmetry for the HVI stimulus is related to the effect of pseudoneglect within the object. It should be noted, however, that this conclusion is 'proven' by demonstrating a null result. Observed power for the interaction was 0.228 and this falls within the lower range of weak-to-moderate power (Cohen, 1988). It is therefore possible that an effect was not found because the test lacked sufficient statistical power.

General discussion

Both experiments showed a clear effect of position for the vertical line. The HVI was strongest in the medial position, replicating the effects observed by Charras and Lupiáñez (2010) and Wolfe et al. (2005). The HVI then declined towards the lateral positions. The decline in the HVI is in line with the bisection bias proposed by Charras and Lupiáñez (2010), which makes the horizontal line look longer.

There was a clear left/right asymmetry within the HVI stimulus for both experiments. This asymmetry was driven partly by a stronger HVI on the left and partly by a stronger reversed HVI on the right. In the discussion of Experiment 1, it was suggested that the reversed HVI could be the result of contextual effects or a misunderstanding of what constituted the vertical line. In addition to these points, the reverse HVI could also be related to asymmetries in the estimation of line length. As outlined in the introduction, when the horizontal line falls to the left or right of the vertical line, its length will be systematically over- or underestimated, respectively, due to the effects of pseudoneglect (Charles et al., 2007). For positions R3 and R4, the large majority of the horizontal line falls to the left of the vertical line, and because of this, its length will be over-estimated. Overestimation of the length of the horizontal line would explain why the reversed HVI is found for the lateral positions on the right side only.

Both experiments also found that the asymmetry within the HVI stimulus was weakest for the medial positions and strongest for the lateral positions. While the pattern observed in both studies was very similar, it should be acknowledged that the interactions themselves were not significant and that effects were only detected with post-hoc comparisons. Despite this, the pattern provides some support for the idea that the asymmetry within the HVI stimulus is related to a misperception of the length of the horizontal line. Thus, for medial positions, the relative proportions of the horizontal line falling to the left and right is roughly similar—resulting in a small difference in length perception. In contrast, for the lateral positions, the relative proportions of the horizontal line falling to the left and right is dissimilar—resulting in a large difference in length perception.

While asymmetries in the estimation of line length provide the most parsimonious explanation of the asymmetry within the HVI stimulus, it appears that a different process is associated with the asymmetry between the stimuli. In this case, the HVI was stronger for presentations to the left hemispace compared to the right hemispace. If the hemispace effect was related to pseudoneglect, it should have interacted with the asymmetry within the HVI. Because no interaction was observed, it appears that the best explanation for the hemispatial effect is an increased susceptibility to geometrical illusions (with the caveat that this conclusion is based on the observation of a null result). Although there is uncertainty in relation to cerebral dominance for illusions (Grabowska et al., 1992), there does seem to be some evidence for hemispheric specialisation for illusions related to length (Clem & Pollack, 1975). The current research supports the idea of right hemisphere susceptibility to illusions—specifically illusions related to length (Clem & Pollack, 1975; Rasmjou et al., 1999; Rothwell & Zaidel, 1990).

It should be acknowledged that a gender imbalance existed in the current study, which reflects the relatively small number of males who undertake undergraduate psychology courses in Australia. While an equal proportion of males and females would have been ideal, there are reasons to suspect that this gender imbalance had minimal effect on the results. A meta-analysis of performance factors in line bisection tasks found that most studies observed a non-significant effect of sex (Jewell & McCourt, 2000). Hausmann (2005), however, has found that fluctuating levels of estradiol throughout females' menstrual cycles may influence the effect of hand-use during a visual line bisection task. Given that the current study did not require participants to make manual line bisections, the effect of estradiol levels may be minimal. Furthermore, Porac, Coren, Girgus, and Verde (1979) examined sex differences for 12 of the most common visual geometric illusions, and observed no effect of gender on illusion magnitude nor illusion decrement. Bearing this literature in mind, it seems that the over-representation of females would have had little impact on the results and that the results should generalise to the broader population.

Previous research has provided useful insights into the mechanisms underlying attentional asymmetries using the Müller-Lyer illusion (Daini et al., 2002; Mattingley et al., 1995; Ro & Rafal, 1996). The current study extended this research to the HVI and has demonstrated that asymmetries arise for the HVI, which are the result of asymmetries in attention *and* asymmetries for illusory geometric effects. It would be interesting to apply this research paradigm to populations with parietal damage and clinical neglect. By manipulating asymmetries within the stimuli and between them, it should be possible to explore line length estimation within and between the left and right hemispaces. The paradigm may also be useful for exploring object- and space-based attentional asymmetries, which are both known to occur in clinical neglect (Driver & Halligan, 1991; Tipper & Behrmann, 1996).

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