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Pseudoneglect and the cross-over effect

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Abstract

Several studies have found that patients with left hemi-neglect bisect long lines too far to the right, but bisect short lines too far to the left (the ‘cross-over’ effect). Some studies have reported that normal participants bisect long lines too far to the left, presumably reflecting an over-estimation of the left side due to the role of the right hemisphere in attention. The purpose of the present series of studies was to further study the cross-over effect in normal participants and to determine whether it may be due to perceptual or motor factors. Participants in the first study showed no cross-over effect on either the traditional line bisection task, or on the purely perceptual Landmark task. However, improvements in the Landmark task in Study 2 did lead to a significant cross-over effect. In Study 3 there was no cross-over on the traditional line bisection task even after changes were made to eliminate the ‘ceiling effect’ that is usually found with very short lines. Overall, the results suggest that normal participants do show a cross-over effect on a purely perceptual task, but not on the traditional manual line bisection task that includes a motor component. Possible implications for models of right hemispheric involvement in attention are discussed. © 2001 Elsevier Science Ltd. All rights reserved.

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It is well known that each cerebral hemisphere in humans is involved in directing attention to the contralateral side of space. The right cerebral hemisphere (RH), particularly the right posterior parietal cortex, seems to be more important for attention than the left. People with right parietal lesions often exhibit ‘unilateral neglect’ and fail to attend to stimuli presented on the side of space contralateral to their lesions, despite intact sensory processing [11,17,22,31,40,47]. One common test for unilateral neglect is the line bisection task. Patients are shown a horizontal line and asked to draw a vertical cross mark through its center. Patients with neglect will typically place the cross mark too far to the right [3,8,9,12,13,15,26,32,37,38,44].

More than one explanation has been offered for why rightward bisection errors occur in neglect patients. One (the ‘perceptual/attentional’ explanation) is that the RH is dominant for directing attention towards

external stimulation, especially on the left side. According to this explanation, the rightward errors on the line bisection task are due to a failure to fully attend to the left side of the line. Thus, the left side of the line appears shorter, and the midline appears to be to the right of true midline. Another (the ‘motor/intentional’ explanation) is that the RH is dominant for directing movement into the left side of space. Under this explanation, the rightward errors on line bisection (and on other tasks) are not due to perceiving the left side of the line as shorter than it really is, but are due to an inability or reluctance to make movements into the left side of space.

Several investigators have attempted to disentangle these two explanations. Some have used the ‘Landmark Task’ [33]. On this task, patients are shown lines that have already been correctly bisected in the center and are asked to indicate which side is shorter either verbally, or by pointing. If the neglect is due to an attentional/perceptual deficit they should point to the left side, because it will appear shorter. If the neglect is due to a motor/intentional deficit, they should point to

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the right side, due to a reluctance to make movements in a leftward direction. Using this method, studies have shown that some patients exhibit a primarily perceptual neglect (i.e. point to the left side), and others a primarily motor neglect (i.e. point to the right side; [3,4,6,15,34]. In addition, Na et al. [37] used a closed-circuit TV system to dissociate the two and found that eight out of 10 patients exhibited the motor form of neglect (they bisected lines to the right even when the right side of the line appeared on the left side of the screen). Adair et al. [1] found that 14 out of 26 patients exhibited primarily perceptual neglect, and the other 12 showed a motor neglect. It has been suggested that the perceptual form of neglect is more likely to result from lesions to the *posterior* right cortex and that motor neglect is more likely to result from lesions to *anterior* right cortex, and that many patients may show a combination of the two [1,5]. However, Bisiach et al. [6] recently reported results from a large series of patients that calls this strict localization into question.

Several studies have found that normal young adults show something that has been called ‘pseudoneglect’. That is, they tend to place the cross mark slightly to the left of true midline on a line bisection task [7,10,13,23,24,33,43]; for a review, see [19]. This finding, which is opposite in direction to that observed in patients with RH lesions, is also thought to result from the RH’s role in attention. The visuo-spatial nature of the task is likely to cause greater cortical arousal in the RH, which in turn leads to a bias of attention to the left side of space [20], and thus an overestimation of the left half of the line (or underestimation of the right). Since the left half of the line appears longer than it actually is, the cross mark is placed slightly too far to the left. However, not all studies of normal participants have found significant pseudoneglect. This is likely due to the relatively small size of the effect, coupled with substantial individual variation in the direction of the bias [25].

Luh [23] suggested that the leftward bias in normal participants may be more of a motor, rather than perceptual phenomenon. When lines were presented on a computer screen and participants had to move the cursor to the middle using a centered mouse (thus reducing movement into the left half of space), they showed no leftward bias. They also showed no significant bias on the Landmark task. However, others have found a significant overestimation of the left half of the line in normal subjects using the Landmark task [29,30,33]. One reason for these conflicting results may be the responses given by participants; Luh allowed her participants to say that the bisection was in the exact center, but the others forced their participants to say that it was either to the left or right.

The cross-over effect is an interesting phenomenon that has been observed in several studies of patients

with neglect [3,8,9,12,13,15,18,26,27,45]. This refers to the fact that when the lines to be bisected are very short (less than 3 cm), the errors made by patients are in the opposite direction, i.e. they place the vertical line too far to the *left*. Some studies have also found a cross-over with the Landmark task [3,27]. Harvey and her colleagues [15] found that the cross-over effect occurred in several patients with the perceptual/attentional type of neglect, but not in one who exhibited the motor/intentional type. However, the perceptual–motor difference in the cross-over effect is not well-established and needs to be studied further.

The cross-over could be due either to an overestimation of the left side of the line, or to an underestimation of the right side (so-called ipsilateral neglect). Chatterjee [8] reported results that strongly suggest that the former is the correct explanation. He presented neglect patients with words and syllables of various lengths. For longer words, they tended to leave out letters on the left, as would be expected of patients neglecting the left side of space. For shorter words, they tended to add letters to the left (e.g. read ‘hu’ as ‘ghu’). If these results are extended to line bisection, they suggest that neglect patients actually perceive the left side of the line as longer than it is. In fact, Tegner and Levander [45] reported that one of their patients said that he perceived a ‘grayish elongation’ of the left side of short lines. These are very interesting results, because the traditional theory of perceptual neglect (that it is due to an underestimation of the size of stimuli on the left) cannot explain why this should be reversed for shorter lines.

To date, there have been no reports of a cross-over effect on a manual line bisection task in normal participants. This is likely due to the fact that very few studies have utilized lines less than 2 cm in length. In fact, there is some evidence for a cross-over on modified line bisection tasks. Laeng, Buchtel, and Butter [21] found a significant cross-over effect using a tactile rod bisection task. Luh [23] appears to have found a cross-over on her computerized line bisection task that was not significant, due to high variability. Finally, McCourt and Jewell [29] found a significant cross-over on a task similar to the Landmark. Since studies of neglect patients have suggested that the cross-over effect may be more likely to occur on a perceptual, rather than motor, task, it is possible that the Landmark task would be more likely to elicit cross-over in normal participants. So, while there is some evidence to suggest that a cross-over effect might occur in normal participants, it is far from well-established, and little is known about the conditions under which it might occur.

The cross-over effect is an important phenomenon, because it is an anomaly under most explanations of neglect. A few models have been advanced as to why it

occurs, but none of these completely explains all of the results observed in normal and neglect patients (for a review, see [35]). In fact, some of the models that have been suggested explicitly predict that normal participants should *not* exhibit a cross-over effect (e.g. [36]). Before any model of the cross-over effect can be evaluated, it will be necessary to determine the conditions under which it occurs in normal subjects.

In the present series of studies we attempted to replicate the cross-over effect found previously in normal subjects on the Landmark task, and to determine whether a cross-over could also be found on the traditional line bisection task, which includes motor, as well as perceptual factors.

1. Study 1

The purpose of this study was to determine whether a cross-over effect could be elicited from normal adults when using lines less than 2 cm long. In order to differentiate between motor and perceptual factors, both a traditional manual line bisection and a Landmark task were administered.

1.1. Method

1.1.1. Participants

Participants consisted of 72 undergraduate students (48 women and 24 men) from Northeastern Illinois University. All participants were right-handed, as assessed by 10-item questionnaire [39]. The mean handedness score was 44.7, with a standard deviation of 3.96, on a scale on which 10 indicates the left hand is always used and 50 indicates the right hand is always used. Ages ranged from 17 to 45, with a median of 23 years. Anyone reporting a history of head injury or other neurological illness was excluded.

1.1.2. Materials

The *line bisection* task consisted of six legal-size pages in landscape orientation. There were five lines on each page; one each of 1, 2, 8, 16, and 28 cm in length. The order of the lines on a page, and the order of pages, were varied pseudo-randomly. Three of the six pages had the lines offset to the left side of the page, and the other three had them offset to the right. Each line on a page was offset a different distance from the edge (from 2 to 6 cm). These offsets were used because, if all lines were centered on the page, their centers would coincide, and participants would be able to use the bisection they made on one line as a guide in bisecting the other lines.

Stimuli for the *Landmark* task were identical to those of the line bisection task, with the exception that each line was already bisected. In addition, there were two more pages with one of each line length. Six lines of

each length were bisected in the exact middle with a 1 cm vertical line. For the rest of the lines, one of each length was transected slightly to the left and one was transected slightly to the right. For the 1 and 2 cm lines the transection deviated 1 mm from center. For the 8 and 16 cm lines it deviated 2 mm from center, and for the 28 cm lines it deviated by 3 mm. Correctly bisected and deviated lines were randomly intermixed. The incorrectly transected lines were included to help to convince participants that the lines were, in fact, not transected in the center, and also to serve as a control to make sure that participants actually could detect a true error.

Extra fine-point pens were provided for marking the lines in the line bisection task.

1.1.3. Procedure

Participants were first asked to sign the consent form and fill out the handedness and a demographics questionnaire. Half of the participants were then tested on the line bisection task, followed by the Landmark task. The other half were administered these two tasks in the opposite order.

For the line bisection task, participants were asked to place a short cross-mark in the exact center of each line on a page, using their right hand. For the Landmark task, participants were told that each line was crossed slightly to the left or right of center. They were asked to indicate the direction in which the cross mark deviated by writing an 'L' or an 'R' on a separate answer sheet. They were not given the option of saying that it was in the center. For both tasks, participants were asked to keep the page centered directly in front of them, and to turn it over before moving on to the next page. As in most previous line bisection studies, viewing distance was not controlled. The distance between participants' eyes and the page ranged from approximately 30 to 50 cm.

Participants were allowed to go through all tasks at their own pace. Most took about 20 min to finish all tasks.

1.2. Results

Preliminary analyses for both tasks showed no main effects or interactions involving sex or order of task administration, so those were not included as variables in further analyses.

1.2.1. Line bisection

The dependent variable for the line bisection task was the error (in mm) in bisecting the line. A negative number was assigned to lines bisected to the left of true center, and a positive number was given to those bisected to the right. The overall mean error score was -0.87 mm, which was almost significantly less than 0, $t(71) = -1.80$, two-tailed $P < 0.08$.

An ANOVA was performed with line length (1, 2, 8, 16 or 28 cm) and side of page (left or right) as repeated measures. There were no significant effects.

Although the group as a whole did not show a significant effect of line length, it is possible that individuals may in fact show biases to the left or right that cancel each other out when all participants are combined into one group. Therefore, participants were divided into two groups based on their overall error score. Those whose overall error score was less than 0 were placed in the 'leftward biased' group, and those whose score was greater than 0 were placed in the

'rightward biased' group. There were 45 participants in the leftward and 27 in the rightward group. This difference was significant, $\chi^2(1, N = 72) = 4.50, P < 0.05$. An ANOVA was performed with bias group as a between-subjects variable and line length and side of page as repeated measures. In addition to the main effect of bias group, there was a line length by bias group interaction, $F(4, 280) = 27.64, P < 0.0001$. Fig. 1 shows that both groups showed increasing errors with increasing line lengths, but that the errors went in the opposite direction.

1.2.2. Landmark

The dependent variable for the Landmark task was the proportion of 'left' choices for each line length on each side of the page, for the lines that were bisected in the center. Note that a 'left' choice indicates that the participant perceived the right side of the line as longer, and is thus analogous to a rightward bisection error. The overall mean was 0.503, which was not significantly different from the 0.5 that would be expected by chance. An ANOVA was performed with line length and side of page as repeated measures. There was a main effect of line length, $F(4, 284) = 3.44, P < 0.01$, which was modified by a length by side interaction, $F(4, 284) = 6.63, P < 0.001$. Fig. 2 shows that participants were more likely to say the line was bisected relatively leftward when the line was on the right side of the page for all lengths but 28 cm, where the difference was reversed.

Since the line bisection analyses had shown that an effect of line length emerged when participants were broken down according to the direction of their bias, the same was done for the Landmark task. Participants who were more likely to say 'left', indicating that they overestimated the right side of the line, were placed in the 'rightward biased' group, and those who were more likely to say 'right' were placed in the 'leftward biased' group. (This seemingly counterintuitive group placement was done to keep the line bisection and Landmark classifications comparable.) There were 34 participants in each group; four showed no bias. The ANOVA reported above was repeated with bias group as an independent variable. There were no significant interactions involving bias group. Fig. 3 shows that the two bias groups showed roughly parallel performance.

Data for the lines that were incorrectly bisected showed that participants could reliably detect the errors. Accuracy rates ranged from 72% correct for 16 cm lines to 90% correct for 1 cm lines.

1.2.3. Correlation between line bisection and Landmark

There was no correlation between overall error on the line bisection and proportion 'left' choices on the Landmark ($r = 0.03$). Furthermore, bias group placement for the line bisection task was not related to bias

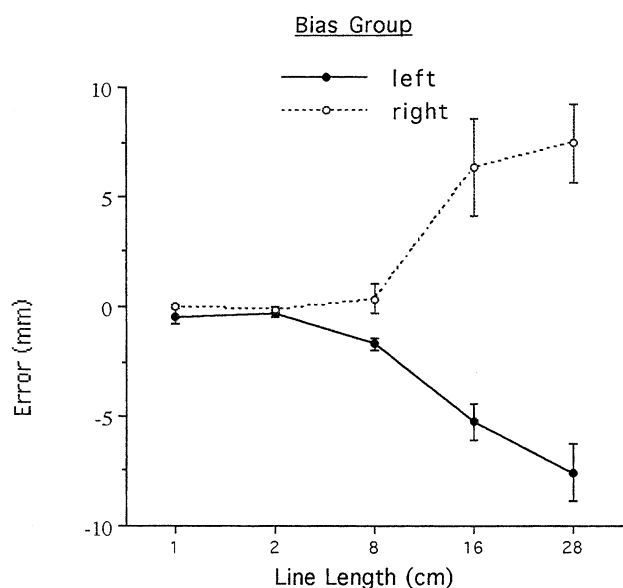


Fig. 1. Study 1. Line bisection errors (\pm standard error) for participants with a leftward and rightward bias. (Negative numbers indicate errors to the left of center.)

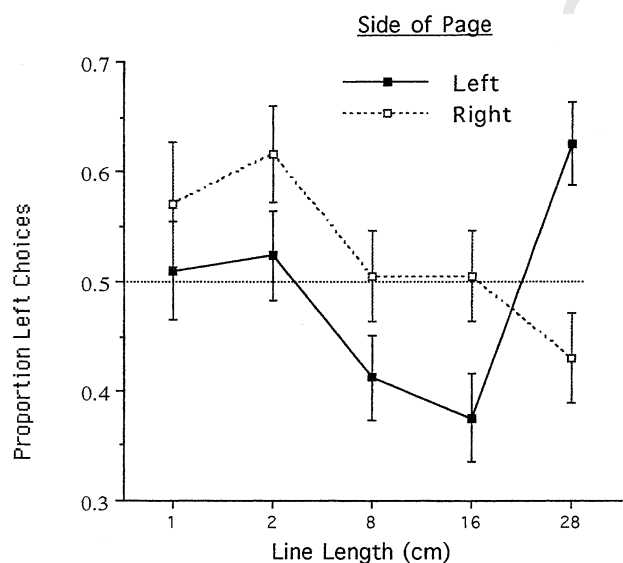


Fig. 2. Study 1. Proportion 'left' choices on the Landmark task, for lines on the left and right sides of the page.

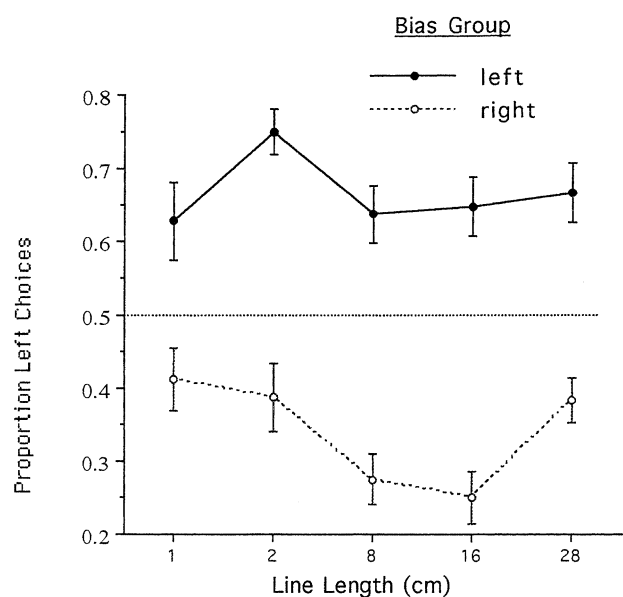


Fig. 3. Study 1. Proportion 'left' choices on the Landmark task, for participants with leftward and rightward biases.

group placement for the Landmark task, $\chi^2(1, N = 68) = 0.249$, n.s.

1.3. Discussion

The results of the present study replicate previous studies that have found a significant leftward bias for line bisection in normal participants [7,10,13,23,24,33,43]. However, the overall leftward bias was not strong, and must be considered in light of the fact that a substantial number (37%) of participants showed a rightward bias. The bias group by line length interaction shows that both groups show increasing errors with increasing line lengths, but in opposite directions. This result is similar to data reported by Manning et al. [25] who found no significant overall bias for normal participants on a line bisection task. However, they did find that individual participants did show reliable biases in the direction of their errors that tended to increase with line length.

The line bisection results showed no indication of a cross-over effect. However, this may be due to a ceiling effect; very few errors were made for the 1 cm lines.

At first glance, the Landmark results appear very confusing. However, the results for lines from 1 to 16 cm do make some sense. Congruent with results reported by others [15,23,29,42], participants were more likely to overestimate the left side of the line (i.e. say it was bisected too far right) when the line was on the left side of the page. Nichelli and Rinaldi [38] reported an opposite effect of side of space, but their effect was only significant for lines longer than 16 cm.

In addition there is some evidence of a cross-over effect; participants made more left choices (indicating

overestimation of the right side of the line) for 1 and 2 cm lines, but made more right choices (indicating overestimation of the left side of the line) for 8 and 16 cm lines. The only data point that does not conform to this general trend is that for the 28 cm lines on the left side of the page. One possible, and admittedly post-hoc, explanation for this is that the 28 cm lines were offset from the left or right side of the page, which was 35.5 cm wide, by 2 cm. Thus, there was very little difference between those on the left and right sides of the page — both were nearly centered. It is possible that participants made their judgments for those lines not based on the lines themselves, but on where they perceived the midpoint of the entire page. This would result in the centered bisections appearing to be too far to the left for lines on the left side of the page, and too far right for lines on the right side of the page, which is what was found (see Fig. 2). This hypothesis could be tested by repeating the study with lines centered on the page.

A final interesting result of this study is the complete lack of correlation between line bisection and Landmark performance. Furthermore, the two tasks showed very different results when participants were divided according to the direction of their bias. For the line bisection task, there was a bias group by line length interaction, due to the fact that participants in both groups showed increasing bias with increasing line length, but in opposite directions (see Fig. 1). For the Landmark task, on the other hand, there were main effects, but no interaction; the two groups showed parallel performance (see Fig. 2). These results suggest that, at least in normal adult participants, the line bisection and Landmark task measure very different aspects of lateral attention.

2. Study 2

The purpose of the second study was to further examine a possible cross-over effect on the Landmark task. The results of Section 1 suggested that there may be a cross-over, but the effect was confounded by the side of the page on which the line appeared. Therefore, in the present study, the same lines were presented centered on the page, with only one line per page.

2.1. Method

2.1.1. Participants

Participants consisted of 61 right-handed undergraduate students (41 women and 20 men) from Northeastern Illinois University. Ages ranged from 17 to 45, with a median of 20 years. Anyone reporting a history of head injury or other neurological illness was excluded.

2.1.2. Materials

Stimuli were identical to those for the Landmark task of Section 1, with the exception that there was only one line, in the center of each page. There were a total of 40 pages. Six lines of each length were bisected in the exact middle with a 1 cm vertical line. One of each length was transected slightly to the left and one was transected slightly to the right. For the 1 and 2 cm lines the cross mark deviated 1 mm from center. For the 8 and 16 cm lines it deviated 2 mm from center, and for the 28 cm lines it deviated by 3 mm. Correctly bisected and deviated lines were randomly intermixed. Between each page with lines, there were two blank pages to insure that the next line could not be seen through the paper. All pages were bound together at the top.

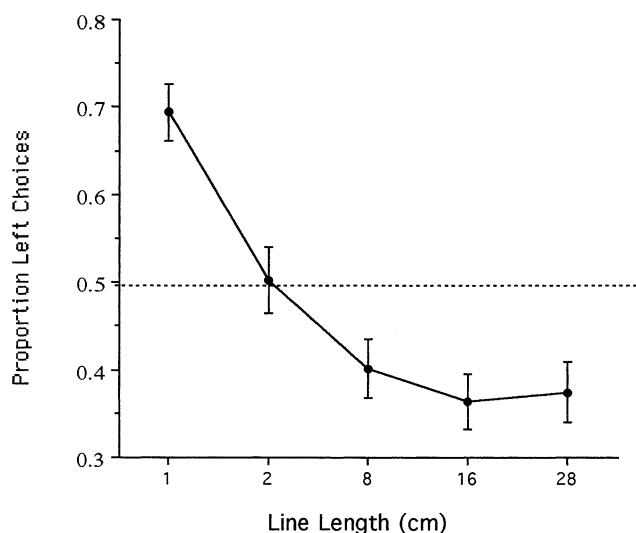


Fig. 4. Study 2. Proportion 'left' choices by line length.

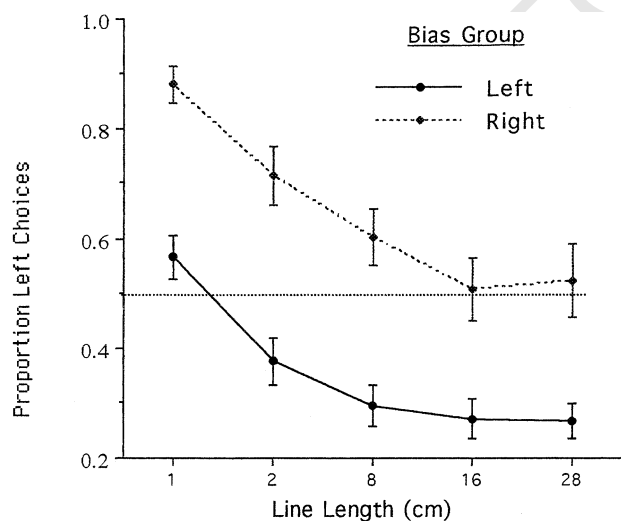


Fig. 5. Study 2. Proportion 'left' choices, for participants who overestimated the left or right sides of the lines.

2.1.3. Procedure

Participants were first asked to sign the consent form and fill out a demographics questionnaire. The stimulus booklet was placed directly in front of the participant, at his/her midline. Viewing distance was not controlled but varied from approximately 30 to 50 cm. Participants were told that each line was crossed slightly to the left or right of center, and were asked to indicate the direction in which the cross deviated by writing an 'L' or an 'R' on a separate answer sheet. Participants were allowed to go through the booklet at their own pace. Most took about 10 min to finish the task.

2.2. Results

The dependent variable was the proportion of 'left' choices for lines of each length that were actually bisected in the center. A score less than 0.5 would indicate an overestimation of the left side of the line (or an underestimation of the right). The overall mean was 0.467, which was not significantly different from 0.50.

Preliminary analyses again showed no sex differences, so that was not included as a variable. An ANOVA was performed with line length (1, 2, 8, 6, or 28 cm) as a within-subjects variable. There was a main effect of length, $F(4, 236) = 18.81, P < 0.0001$, which is depicted in Fig. 4. Separate *t*-tests were conducted for the mean at each length, to determine whether it was significantly different from 0.5. The mean for the 1 cm lines was significantly greater than 0.5 (indicating an overestimation of the right side of the line), and the means for the 8, 16, and 28 cm lines were significantly less than 0.5 (indicating an overestimation of the left side of the line; all P s < 0.05 , with Bonferonni correction). The mean for the 2 cm lines did not differ significantly from 0.5.

As in Section 1, participants were broken down according to whether they had a bias to report the center-bisected lines as bisected to the left or right. Twenty-one participants who were more likely to say 'left', indicating that they overestimated the right side of the line, were placed in the 'rightward biased' group, and 35 who were more likely to say 'right' were placed in the 'leftward biased' group. Five participants showed no overall bias. The ANOVA reported above was repeated with bias group as an independent variable. There were no significant interactions involving bias group. Fig. 5 shows that, as in Section 1, the two bias groups showed parallel performance.

For the lines that were actually bisected to the left or right, accuracy was at least 80% for all lengths except for the 16 and 28 cm lines that were bisected to the left. For these, the accuracy rates were 62 and 47%, respectively. This shows that participants were generally able to perceive inaccuracies in bisection, except at the longest lengths, when accuracy was slightly impaired by the tendency to overestimate the left side of the line.

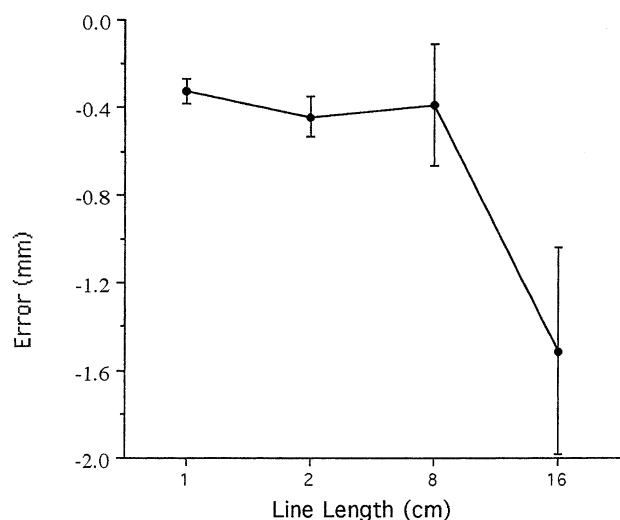


Fig. 6. Study 3. Line bisection errors (mm) as a function of line length.

2.3. Discussion

The most important result of Section 2 was that a significant cross-over effect was found with the Landmark task. Congruent with previous studies of normal participants [29,30,33], there was a significant overestimation of the left side of the 8, 16, and 28 cm lines. In addition, there was a significant *underestimation* of the left side of the 1 cm lines. This replicates results reported by McCourt and Jewell [29].

Another interesting result of this study is the nearly parallel performance by participants with leftward and rightward biases. Despite the large difference in the overall mean for the two groups, both show a similar cross-over pattern with opposite performance for the short and long lines (Fig. 5). This is in stark contrast to the mirror-image pattern of performance for the two bias groups on the line bisection task in Section 1 (Fig. 1). This lends further support to the idea that the line bisection and Landmark tasks are measuring very different things in normal participants.

3. Study 3

The results of Section 1 and Section 2 suggest that normal young adults exhibit a cross-over effect on the purely perceptual Landmark task, but not on the traditional line bisection task. However, the lack of a significant cross-over effect on the line bisection task in Section 1 may be due to a ceiling effect. In Section 3 we administered a line bisection task and sought to increase errors by encouraging participants to work faster.

3.1. Method

3.1.1. Participants

Participants consisted of 38 right-handed undergraduate students (32 women and six men) from Northeastern Illinois University. The mean score on the handedness questionnaire was 46.6 and the standard deviation was 4.02. Ages ranged from 18 to 46, with a median of 22 years. Anyone reporting a history of head injury or other neurological illness was excluded.

3.1.2. Materials

Only the line bisection task was administered in this study. Stimuli consisted of half-sheets of paper (8.5" by 5.5") with a line in the center of each page. The lines were 1, 2, 8, or 16 cm long (the 28 cm lines were not included because the main focus of this study was on short lines). Six of each length were randomly intermixed, for a total of 24 lines. These were broken down into three blocks with eight lines in each block. Stimulus pages were bound together with ring binders at the top. A blank page was included between each page with a line, so that the line on the next page would not show through.

A stopwatch was used to record participants' times.

3.1.3. Procedure

After signing the consent form and filing out the demographics questionnaire, participants were given a booklet of lines. They were told that there would be one line on each page, and that they were to put a cross-mark through the exact middle of each line, using their right hand. They were also told that their performance would be timed, and that accuracy and time were equally important. At the end of a block of trials (i.e. after bisecting eight lines), participants were told their time, and encouraged to try to improve on that time in the next block of trials.

3.2. Results

Due to the low number of men in the present study, and the fact that the previous studies found no sex differences, sex was not included as a variable in the following analyses.

The dependent variable was the error (in mm) in bisecting the line. A negative number was assigned to lines bisected to the left of true center, and a positive number was given to those bisected to the right. The overall mean error score was -0.667 mm, which is significantly less than 0, $t(37) = -3.57$, $P < 0.01$.

A repeated measures ANOVA showed a significant effect of line length, $F(3, 111) = 5.55$, $P < 0.01$. Fig. 6 shows that scores became more negative with increasing length. Separate t -tests were performed to determine whether the scores at each length were significantly less

than 0. All were significant except the scores for 8 cm. However, closer inspection of the data suggests that the lack of a significant leftward bias for 8 cm lines is due to the high variability, rather than a difference in the mean (see Fig. 6).

As in Section 1, participants were broken down into two groups based on whether they had an overall leftward or rightward bias. Those whose overall mean error score was less than 0 were placed in the 'leftward' group, and those whose mean was greater than 0 were placed in the 'rightward' group. There were 25 participants in the leftward group and 13 in the rightward. This difference did not quite reach a conventional level of significance, $\chi^2(1, N = 38) = 3.79, P < 0.10$. An ANOVA with bias group as a between-subjects variable and line length as a within-subjects variable showed a significant interaction, $F(3, 108) = 23.06, P < 0.0001$. Fig. 7, which is very similar to Fig. 1, shows that the difference between the two groups increased with increasing line length.

3.2.1. Study 1 and 3 combined analyses

To determine whether the changes in the stimuli and the timing of participants in Section 3 resulted in differences in error patterns, analyses were conducted comparing their performance to the line bisection performance for lines of 1–16 cm for Section 1. An ANOVA with study as a between-subjects variable and line length as a within-subjects variable showed no significant main effect or interaction. This is surprising, since significant effects had been found in Section 3, but not Section 1. In fact, the timing of participants in Section 3 did not lead to a significant increase in errors; the overall mean for Section 3 was -0.667 mm, com-

pared to -0.603 mm for Section 1, $t(108) = 0.12, P = 0.904$. The differences between the two studies seems to be due mainly to a drastic reduction in error variance for Section 3. The overall variance for Section 3 was 1.33, and for Section 1 it was 9.62, Levene's $F(1, 108) = 8.70, P < 0.005$.

3.3. Discussion

The main result of Section 3 was a replication of the results from the line bisection task in Section 1. All of the changes made to the stimuli and procedure (timing, the placement of the lines on the page, etc.) resulted in only a small increase in errors, but a rather large reduction in variability, and no overall change in the pattern of performance. There is clearly not a cross-over effect for normal participants on the traditional line bisection task. The lack of cross-over cannot be due to lack of statistical power; there was a statistically significant leftward bias even at the shortest line length. This is the first study to show a significant leftward bias for lines as short as 1 cm. It might be argued that the group exhibiting an overall rightward bias does appear to show a cross-over (see Fig. 7). However, there were only 13 subjects in that group, and the effect is in the opposite direction from what occurs on the Landmark task.

The reduction in error variance in Section 3 is not surprising, given that there are probably numerous strategies a participant could use in performing the line bisection task. In fact, in Section 1 some participants were observed trying to use their fingers or pen to 'measure' the line and had to be asked not to do so. Encouraging participants to work faster by timing them probably reduces the range of strategies that are available, and consequently, a reduction in variability is observed.

4. Overall discussion

In Section 2 we have replicated the cross-over effect that was previously found for normal participants on the Landmark task, [29]. However, in Section 1 and Section 3 we have also shown that it does not occur on the traditional manual line bisection task. This suggests that the cross-over is due to some sort of perceptual/attentional factor, as opposed to a motor/intentional factor. This result may appear to be in contrast with the studies of neglect patients, which have frequently reported that they exhibit a cross-over for line bisection. However, Harvey and her colleagues [15] found that the cross-over effect occurred in several patients with the perceptual type of neglect, but not in one who exhibited the motor type. None of the other studies reporting a cross-over have differentiated between perceptual and

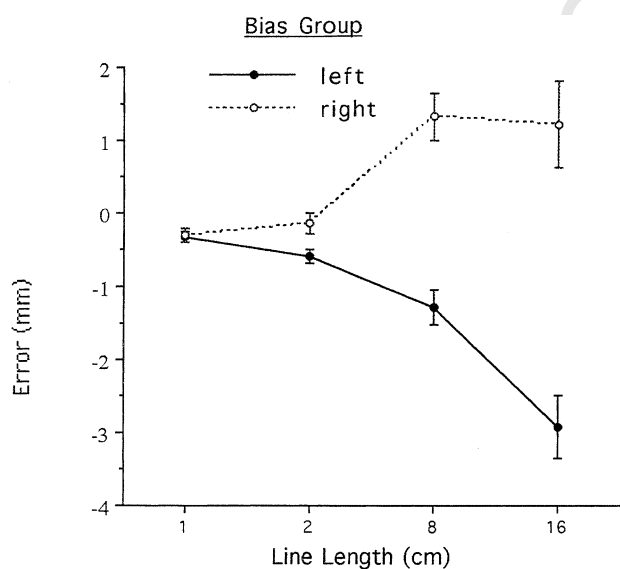


Fig. 7. Study 3. Line bisection errors (mm) for participants with leftward and rightward biases.

motor factors. Many patients exhibiting the motor form of neglect also show some evidence of perceptual deficits as well, [1,6], so a cross-over might be expected in most cases.

The complete lack of correlation between bias scores on the line bisection and Landmark tasks found in Section 1 is also surprising given that previous studies of neglect patients [4,6] and normal participants [10,23] have typically reported statistically significant correlations between the two tasks. However, the correlations reported for normal participants in the past have been quite low. Furthermore, in a recent study by Seki, Ishiai, Koyama, and Sato [44], the authors asked neglect patients to verbally report on the accuracy of their own (rightward) bisections. When asked whether the cross mark was in the center of the line, all 32 patients reported that it was. However, when asked to point to the longer side, all but one patient indicated that the two sides were unequal. Most of them correctly pointed to the left side. This suggests that verbal report and pointing may be dissociable tasks. Furthermore, Harvey and Milner [14] reported results from two neglect patients who exhibited comparable neglect on both tasks when tested 2 months after their stroke. When tested 10 months later, both showed substantial improvement on the line bisection task, but continued to exhibit significant neglect on the Landmark.

More information about the nature of the differences between the line bisection and Landmark tasks can be gained by examining the different pattern of results found when participants were divided based on whether they showed an overall leftward or rightward error pattern. In both Section 1 and Section 3, there were more participants making leftward errors, suggesting a RH dominance in performing the task. However, a substantial minority (37% in Section 1, 34% in Section 3), exhibited a rightward bias. For both groups, the bias became greater as the lines got longer. These results are similar to those reported by Manning et al. [25], who also found substantial individual variation. This may explain why it is so difficult to obtain statistically significant leftward biases for this task. It also suggests that either hemisphere can dominate on the line bisection task (although there is a tendency for the RH to dominate), and that each hemisphere performs the task in the same way, resulting in a greater lateral deviation for longer lines.

On the Landmark task, there was no difference in the number of participants showing an overall leftward or rightward bias in either Section 1 or Section 2. This may be due to the fact that participants tended to overestimate the right side of short lines, and overestimate the left side of long lines. The two bias groups showed parallel effects of line length:

both showed increasing overestimation of the left side as the lines got longer.

Now that the cross-over effect on the Landmark has been firmly established for normal participants, any theory of why it occurs in neglect patients will also have to explain why it occurs (in the opposite direction) in normal participants.

Although several authors have attempted to explain the cross-over effect, none of them have been able to fully account for all of the data. (For a review, see [35].) Some have attempted to simulate neglect and the cross-over with connectionist-type models in which the input is a line and the output is some sort of representation of the line [2,35,36]. The center of gravity of the represented line is taken to be the bisection point. Each of these models accounts for the cross-over in a different way. Mozer et al. assume that the slight leftward bias observed in normal participants is completely separate from, and additive with, the rightward bias shown by neglect patients. Since neglect patients' rightward biases become less severe as lines get shorter, there should be some line length at which there is no bias due to neglect. At this length, the normal leftward bias will result in a cross-over. This model cannot accommodate the results of the present study. Although our normal participants did exhibit a leftward bias for short lines on the line bisection task, unlike the cross-over observed in neglect patients, this leftward bias *decreased*, rather than increased, as the lines became progressively shorter. Furthermore, on the Landmark task, our normal participants underestimated, rather than overestimated, the left side of short lines.

The models of Anderson [2] and Monaghan and Shillcock [35] do not rely on a separate leftward bias in normal subjects to explain the cross-over. Rather, the cross-over emerges out of the same model used to explain the rightward bias for longer lines. In Anderson's model it is due to an asymmetry in the 'saliency' gradients of the left hemisphere (LH) and RH. Their model explains why neglect is more severe after RH lesions, but makes the incorrect prediction that with extremely short lines, performance should cross-over again and bisections should deviate to the right. In Monaghan and Shillcock's model the cross-over emerges as a result of a release from inhibition and the addition of noise to the damaged hemisphere. Their results seem to better match the performance observed in neglect patients with extremely short lines, but under this model the effects of LH and RH lesions are symmetric. For both of these models, various parameters have been set so that the unlesioned performance is near perfect. However, unlike Mozer et al.'s model, these could probably be modified to simulate the cross-over observed in normal participants for the Landmark task.

Most previous explanations of neglect and pseudoneglect have postulated that they are both due to the RH's role in attention. This causes a slight bias in attention towards the left in normal participants, which results in an overestimation of the length of the left half of the line (or an underestimation of the right half). The damage to the RH in neglect patients results in a tendency to pay more attention to the right half of the line, and thus, to overestimate its length (or to underestimate the length of the left half). The implicit assumption here is that lines in the attended field appear longer. If this assumption is true, then in order to explain the cross-over effect we must further assume that, for some reason, normal participants pay more attention to the right side of a short line. Of course this is possible. However, it seems highly implausible that patients with RH lesions would pay more attention to the *left* side of a short line.

An alternative explanation is that normal participants always pay more attention to the left side of a line, and neglect patients always pay more attention to the right. Under this hypothesis, lack of attention would lead to an underestimation of the length of long lines, but an overestimation of the length of short lines. This may seem counterintuitive, but there is some evidence for this. Werth and Poppel [48] found that normal participants tend to underestimate the length of long (20 cm) lines, and overestimate the length of short (4 cm) lines. It is possible that this pattern of errors would be attenuated by increasing attention, but exaggerated by decreasing attention. Some evidence for this has been reported by Tegner and Levander [45] who had neglect patients indicate the length of a horizontal line by drawing a vertical line of equal length. They found that they tended to overestimate the length of the short lines and underestimate the length of long lines to a greater degree than normal participants.

Furthermore, Tsal and Shalev [46] asked normal participants to estimate the length of vertical lines and manipulated attention by presenting cues. They found that unattended lines were perceived as longer than they actually were. Interestingly, all the lines they used were less than 2 cm in length. In a recent study, Harvey and her colleagues [16] used invisible cues to draw normal participants' attention to one side of the line on a Landmark task, and found that this resulted in an underestimation of the unattended side. All lines used in that study were 20 cm. Thus, there is some evidence that attention tends to increase the perceived length of long lines, but decrease the perceived length of short lines.

This effect of attention on perceived length can also explain the cross-over effect if we further assume that the RH is more involved in attention than the LH. In

normal participants, slightly less attention would be directed to the right side of the line, and that would lead to an overestimation of the right side for short lines, but an underestimation for long lines. There is evidence for visual field differences in normal subjects' line length estimation that is congruent with this. In one of Tsal and Shalev's [46] studies (Experiment 5) the lines were lateralized, and they found that those in the right visual field tended to be perceived as longer than those in the left visual field. This is entirely consistent with the results found for 1 cm lines in our Section 2. In another study, Masin and Sartori [28] presented pairs of vertically-oriented lines and found that normal participants tended to overestimate the length of the line on the left, relative to the line on the right. Their lines ranged from 8 to 12 cm, and their results are congruent with the results obtained for lines in that range in our Section 2. It must be noted that Prinzmetal and Wilson [41] have suggested that the attentional effect found by Tsal and Shalev might actually be due to a spatial interaction between the cue and the stimuli, rather than attention. However, this explanation could not account for the visual field differences they report.

To summarize, the results of the present study show that a cross-over effect does occur in normal adults on the Landmark task, but not on the traditional line bisection task. Further study will be necessary to better understand the conditions under which it occurs, and possible explanations for why it occurs. For example, since the stimuli in this study (and virtually all previous line bisection studies) have been presented in free vision, it is not possible to determine whether the important variable is the actual length of the line or the visual angle it subtends. McCourt and Jewell [29] did keep the viewing distance constant in their normal participants, and found that the cross-over occurred at a visual angle of 2.95°. However, they did not vary viewing distance to determine whether that would have any effect. One study that did vary viewing distance in neglect patients found that both the absolute length of the lines, and the visual angle subtended affected the length at which the cross-over occurred [18]. In another interesting study of neglect patients, Marshall et al. [27] found that the length of the line at which the cross-over occurred depended on the lengths of the other lines in a block of trials. This suggests that the context in which lines appear is also an important factor to be taken into account.

Clearly, more work needs to be done in this area to determine which variables affect the cross-over, and whether they have similar effects in normal participants and neglect patients. Further study of hemispheric differences size estimation and the effects of attention are also needed.

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