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Crossover is not a consequence of neglect: A test of the orientation/estimation hypothesis

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Abstract

Most patients with neglect demonstrate a crossover effect on line bisection. Crossover refers to a pattern of performance in which long lines (>10 cm) are bisected ipsilateral to brain injury and short lines (<2 cm) are bisected contralateral to brain injury. Crossover bisections on short lines are of interest because they are not predicted by contemporary theories concerning neglect. However, we propose that the effect depends on two independent factors that normally influence bisection performance but are merely exaggerated in neglect—a tendency to overestimate the length of short lines and underestimate long lines and a tendency to orient attention preferentially in one spatial direction. We predicted that both patients with unilateral left and right hemisphere injury would demonstrate crossover on line bisection and that they would overestimate short lines and underestimate long lines upon direct visual inspection. Further, the 2 groups were predicted to demonstrate crossover in opposite directions owing to different lesion-induced biases in attentional orientation. Testing 5 patients with right hemisphere injury and 7 patients with left hemisphere injury confirmed each prediction. Additionally, errors in length estimation were exaggerated among patients with right hemisphere injury, most of whom had neglect. It is concluded that while crossover is accentuated in cases of neglect, it is not a consequence of neglect *per se*. As such, crossover bisections are not at odds with contemporary neglect theory. (*JINS*, 2002, *8*, 107–114.)

Keywords: Neglect, Orientation, Magnitude estimation, Line bisection, Attention, Confabulation

INTRODUCTION

Spatial neglect (or simply neglect) is defined as the failure to respond, orient or act on stimuli located contralateral to a focal brain injury (Heilman et al., 1985). Neglect is theoretically linked to deficits in contralateral sensory attention, motor intention, or mental representation (Bisiach 1993; Bisiach & Luzzatti, 1978; Heilman & Van Den Abell, 1980; Kinsbourne, 1970; Mesulam, 1981; Posner & Dehaene, 1994; Watson et al., 1978). Most patients with neglect demonstrate a seemingly paradoxical behavior on line bisection known as the crossover effect (Chatterjee et al., 1994a; Halligan & Marshall, 1988; Marshall & Halligan, 1989; Tegner & Levander, 1991). When given a range of line lengths to bisect (e.g., 1–30 cm), they bisect long lines on the same side of true center as their brain lesion (i.e., ipsilesional errors) and short lines on the opposite side of true center (i.e., contralesional errors). Crossover bisections are considered paradoxical with regard to neglect theory (Anderson, 1997) because they suggest either productive errors or ipsilesional neglect. The importance of resolving crossover phenomena has been alluded to by Bisiach et al. (1994), who described crossover as "a repressed pain in the neck" for neglect theorists.

Crossover bisections on short lines have been attributed to productive errors among patients with neglect. Tegner and Levander (1991) examined 25 patients with right hemisphere injury and found contralesional errors on small stimuli to be as common as ipsilesional errors on large stimuli. Additionally, when compared with nonpatient control subjects, patients with right hemisphere injury manually reproduced small lines (e.g., 2 cm) as longer than the objective length and long lines (e.g., 20 cm) as shorter than the objective length. Chatterjee (1995) examined 5 patients with

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neglect dyslexia, the inability to report or read contralesional portions of words, sentences, or paragraphs. His patients read letter strings (both words and nonwords) that varied in length from two to eight letters and bisected lines that ranged in length from 2 to 24 cm. Four patients demonstrated crossover on line bisection and, when reading letter strings, they read long strings as shorter than the objective length and short strings as longer than the objective length. Both studies led to the conclusion that crossover bisections relate to confabulation and/or completion in neglect. The Tegner and Levander (1991) study showed, as well, that patients with neglect made greater errors estimating stimulus magnitude than did nonpatient control subjects.

Crossover bisections on short lines have also been attributed to normal performance. Marshall and Halligan (1989) and Mozer et al. (1997) posit that crossover bisections in neglect reflect a contrast between abnormal performance on long lines, which are bisected right of true center, and normal performance on short lines, which are bisected left of true center. They suggest that patients with neglect are less able to judge the true center of long rather than short lines and that patients scan long lines from right to left and short lines from left to right. Patients are presumed to exhibit little or no neglect on short lines and to bisect them left of true center consistent with reports of pseudoneglect among normal subjects (Bowers & Heilman, 1980; Bradshaw et al., 1987; Jewell & McCourt, 1999). However, this explanation is not entirely consistent with data derived in studies of normal subjects. First, McCourt and Jewell (1999) found that young, normal male subjects who show pseudoneglect on long lines actually crossover to the right of true center on short lines. Marshall and Halligan's (1989) hypothesis would predict the opposite result on short lines. Next, in a paper examining normal variation in line bisection performance, Manning et al. (1990) argued that normal subjects may scan short and long lines from either left to right or right to left and, once oriented, they may either overshoot or undershoot the true center of the lines resulting in any and all patterns of bisection performance. Given the latter conjecture, it is not clear why the majority of patients with right hemisphere injury and neglect should consistently bisect short lines to the left of true center if they are merely performing normally.

Most explanations of the crossover effect are predicated in some manner on neglect following right hemisphere injury (Anderson, 1996; Chatterjee, 1995; Kinsbourne, 1993; Marshall and Halligan, 1989; Marshall et al., 1998; Mozer et al., 1997; Tegner & Levander, 1991). In contrast, Mennemeier et al. (1998) proposed that the crossover effect results from normally occurring biases in attentional orientation and from systematic errors in magnitude estimation (i.e., the orientation/estimation hypothesis). Accordingly, subjects orient attention preferentially to the same end of all lines prior to bisection and then systematically overestimate the length of short lines and underestimate long lines (see Figure 1). Attentional orientation serves to anchor mental representations of the line, and systematic errors in length estimation actually cause bisection marks to fall short of true center on long lines and to go beyond true center on short lines. Both factors are merely exaggerated in cases of neglect. For example, right hemisphere injury induces a strong orientation bias (Kinsbourne, 1970) toward the right

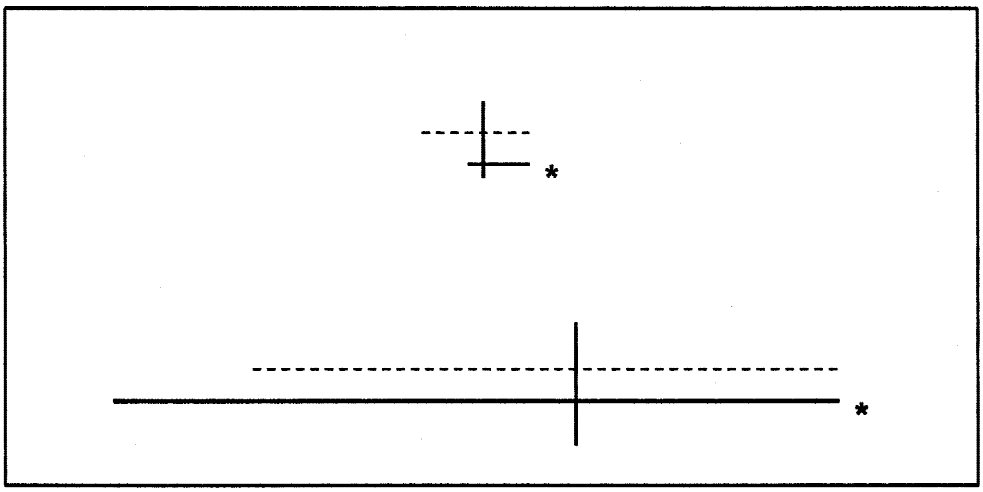


Fig. 1. According to the orientation/estimation hypothesis of crossover, subjects accurately bisect an anchored, mental representation of the line which leads to misplacement of the physical bisection mark. Solid lines represent the true line length. Dotted lines represent the mental representation or perceived length. Asterisks represent attentional orientation. If a subject orients attention to the right end of the line and overestimates its true length, the physical bisection mark falls left of true center (short line, top of figure). If the subject orients to the right and underestimates true length the physical bisection mark falls right of true center (long line, bottom of figure). Orienting to the opposite end of the lines, as proposed for patients with left hemisphere lesions, would reverse the direction of the physical bisection error on short and long lines.

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end of lines, and the normal tendency to underestimate long lines and overestimate short lines is also exaggerated, resulting in a robust right-to-left crossover effect (Mennemeier et al., 1998).

Marshall et al. (1998) have proposed a similar explanation of the crossover effect; however, they view crossover as specific to neglect and argue, as well, that length estimation errors stem from exaggerated stimulus context effects. Context effects refer to a type of regression bias in judgment in which estimates of line lengths migrate toward the arithmetic mean of the range of line lengths presented for judgment. However, it is presently unknown whether contextual effects, which are are small in studies of normal subjects (Cross, 1973), may explain all or only part of the variance associated with magnitude estimation among patients with neglect.

The orientation/estimations hypothesis differs from other explanations in both its applicability to normal bisection performance and in the predictions that it makes. For example, if the crossover effect is a normal phenomenon that stems from systematic errors in length estimation (Mennemeier et al., 1998, 1999), then patients with left hemisphere injury, as well as patients with right hemisphere injury, should underestimate the length of long lines and overestimate short lines upon direct measures of length estimation. Additionally, if attentional orientation determines the direction of line bisection errors on short and long lines, then patients with right- and patients with left-hemisphere lesions should crossover in opposite directions because their brain lesions would impose orientation biases in opposite directions (Kinsbourne, 1970, 1993). Finally, the direction of errors on line bisection should converge with estimates of length for both patient groups—ipsilesional errors should correspond with underestimates of line length and contralesional errors with overestimates of length. Neglect is predicted to accentuate errors in magnitude estimation (Anderson, 1997; Tegner & Levander, 1991) and to lead to a stronger bias in attentional orientation (Kinsbourne, 1970, 1993) thereby exaggerating the crossover effect relative to patients without neglect.

METHODS

Research Participants

Subjects were 12 patients with unilateral brain lesions due to stroke. Five had unilateral right hemisphere lesions (RHL) and 7 had left hemisphere lesions (LHL; Table 1). All patients were tested at least 2 months post stroke onset. The average lesion chronicity for RHL patients was 11 months (SD = 6.6) and 20 months (SD = 14.4) for LHL patients, but the difference was not statistically significant. Clinically obtained MRI or CT studies were available for 4 of the RHL patients and 3 of the LHL patients. Neuroradiologic reports were used to confirm unilateral lesion involvement in those patients whose films were not available. Template mappings for the 4 RHL patients and the 3 LHL patients have been published elsewhere (patients are identified across papers by code number; Mennemeier et al., 1997, 1998). Here, the information on lesion location is summarized in Table 1.

Both groups of subjects had a mean age of 65 years (RHL: SD = 10.7; LHL: SD = 13.6). All of the RHL patients were

Table 1. Data for individual subjects

			Bisection		Estimation					
Subject	Site	Location	Function	R^2	Function	R^2	L.B.	L.C.	E.	Draw
56	Left	tpr	$1.18(L)^{.096}$	100	$.81(L)^{.099}$	97	−	−	−	−
47	Left		$1.10(L)^{.097}$	100	$1.08(L)^{.099}$	99	−	−	+	−
48	Left	r, fo,ltmp	$1.05(L)^{.097}$	100	$1.41(L)^{.094}$	97	−	−	−	−
46	Left		$1.03(L)^{.098}$	100	$1.11(L)^{1.00}$	99	−	+	−	+
55	Left	ltmp, smg, ang	$1.05(L)^{.099}$	100	$1.54(L)^{.092}$	100	−	−	−	−
51	Left	bg	$.97(L)^{1.00}$	100	$1.24(L)^{.092}$	100	−	−	−	−
44	Left		$.99(L)^{1.00}$	100	$.99(L)^{1.06}$	99	−	−	+	+
50	Right	r, ltmp, smg	$1.15(L)^{.091}$	100	$1.44(L)^{.091}$	99	+	−	+	−
54	Right	neg CT	$.92(L)^{.092}$	100	$1.42(L)^{.087}$	99	+	+	+	+
53	Right	r, fo, ltmp, smg, ang, lsp	$1.06(L)^{.093}$	99	$1.62(L)^{.086}$	99	+	+	+	−
49	Right	r, ltmp, smg, lsp	$.94(L)^{.094}$	99	$1.04(L)^{.093}$	99	+	+	+	+
52	Right	ic, bg	$1.03(L)^{1.02}$	100	$1.00(L)^{.098}$	98	+	+	−	+

Note. Table 1 provides lesion information, power function parameters for bisection and length estimation tasks, the variance accounted for by each function, and performance on tests of neglect for each subject in this study. Subject refers to the subject code number. Site refers to lesion laterality. Location refers to lesion location within the damaged hemisphere (see letter codes below). Function refers to parameters of the power function as follows: constant (Line Length) $^{\text{exponent}}$. R^2 refers to the amount of variance accounted for by the regression equation. Tests for neglect are as follows: L.B. = line bisection, L.C. = line cancellation, E. = contralesional extinction to double simultaneous stimulation, and DRAW = drawings of a daisy and of a clock. A negative sign (−) indicates no evidence of contralesional neglect, a positive sign (+) signals the presence of neglect. Lesion location was coded as follows: r = rolandic, fo = frontal operculum, ltmp = lateral temporal gyri, bg = basal ganglia, smg = supramarginal gyrus, ang = angular gyrus, lsp = lateral superior parietal lobe, ic = internal capsule, tpr = temporal parietal region (neuroradiologic report only) and neg CT = a negative CT study at the time of hospital admission.

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right hand dominant by report. Six of the LHL group were right hand dominant. Men predominated the subject pool (9/12 subjects) but were evenly distributed across groups. One RHL subject had a left homonomous hemianopsia due to stroke, and one LHL subject was blind in his right eye. The remaining subjects did not demonstrate visual field defects to bedside confrontation exam. Symptoms of aphasia were not formally assessed; however, we did not include any patient who could not fully comprehend instructions and provide meaningful, unambiguous verbal responses.

The study was approved by the University's Institutional Review Board. All subjects gave informed consent prior to entry and subsequently participated in a series of prospective investigations of the neglect syndrome (see also Mennemeier et al., 1997, 1998).

Apparatus

Line length estimation

There were 26 lines ranging in length from .3 to 78.75 cm. Each line was .2 cm in width. All but the two longest lines were presented in black-on-white strips of paper measuring 7.6 × 35.6 cm. The two longest lines were presented in black-on-white boards measuring 21.6 × 101.6 cm.

Line bisection

There were eight lines ranging in length from .5 to 78.75 cm. They also were .2 cm in width. All but the two longest lines were presented in black on white legal-size paper. The two longest lines were presented in black on white boards measuring 21.6 × 101.6 cm.

Stimuli in both experiments were presented on the same white table top (121.9 × 91.4 cm) to provide a uniform background for all stimuli.

Procedure

Prior to the experiment, patients were screened for evidence of neglect using line bisection (20 and 30 cm lines); a 64 line cancellation test; tests for extinction to double simultaneous stimulation in the auditory, visual and tactile sensory modalities; and a clock and daisy drawing test (see Table 1). These tests were selected from a battery of tests sensitive to neglect that was used in previous studies (Mennemeier et al., 1997, 1998). Neglect was defined as line bisection errors more than 2% of the total line length, more than 2 contralateral omissions on the line cancellation test, any instance of extinction to double simultaneous stimulation in any sensory modality, and contralateral errors of omission on drawings. These criteria were established by normal subjects in previous studies (Mennemeier et al., 1997, 1998). They either exceed 99% confidence limits set by normal subjects (i.e., line bisection and cancellation) or represent behaviors that were not observed among normal subjects (i.e., extinction and drawing errors of omission). During the present experiment, lines were presented one at a time and placed horizontally, 30 cm directly in front of the patient. The sequence of line lengths was randomly determined; however, all line length estimation and all line bisection trials were conducted together, yet on separate occasions.

For line length estimation, patients were instructed to look at each line and estimate its length in inches because inches were more familiar to our subjects than centimeters. Patients were encouraged to be as specific as possible using decimals or fractions when necessary. There was one trial for each line length.

For line bisection, patients were instructed to use a pen to place a small vertical mark at the midpoint of each line that would divide the line into two equal parts. There were three trials for each line length. Subjects used either their preferred hand (if possible) or the hand unaffected by stroke. Emphasis was placed on getting the most accurate performance.

Statistical Analyses

The independent variable for both data sets was the objective line length. The dependent variable for length estimation was the patient's verbal report of line length in inches. For line bisection, it was twice the distance from the ipsilesional end of the line to the bisection mark. We assumed that patients orient attention ipsilesionally and attempt to bisect the line (Chatterjee, et al., 1994a, 1994b; Mennemeier et al., 1997, 1998), so this calculation provides an estimate of the perceived total line length.

Data were summarized by use of a power function and were plotted graphically. Power functions are commonly used in psychophysical studies of magnitude estimation (Stevens, 1970, 1971; Stevens & Galanter, 1957). The dependent and independent variables are logarithmically transformed to permit graphing as a straight line, and the dependent variable is statistically regressed on the independent variable. The slope of the regression line is equivalent to the exponent of the power function (Chatterjee et al., 1994a, 1994b). The exponent summarizes the relationship between perceived stimulus magnitude and objective magnitude—in this case, line length. Regression also yields a constant which is equal to the *y*-intercept value. The constant has been related to "scaling factors" without greater elaboration (Stevens, 1971). When perceived length closely matches objective length, the exponent and constant are close to one (Stevens & Galanter, 1957). If the exponent is decreased and the constant increased, a systematic bias is indicated—that is, overestimating short lines and underestimating long lines. The power function exponent for estimates of length in normal subjects is 1 (Stevens & Galanter, 1957). However, the exponent is typically less than 1 for patients with neglect and their constant is typically greater than 1 (Chatterjee et al., 1994a, 1994b). Thus, the size of the exponent and constant can be used as markers of the degree to which perceived stimulus intensity is altered by

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either experimental or nonexperimental factors, in this case—lesion laterally and neglect.

We first examined whether or not the exponents and constants for RHL and LHL patients were different from 1 by establishing 95% confidence limits. Next, exponents and constants were compared using a mixed model ANOVA with group (RHL *vs.* LHL) as the between-subjects variable and task (line length estimation *vs.* line bisection) as the within-subjects variable. To plot the data, raw estimates of line length were divided by the objective line length and then converted to *z* scores so the data for each group could be compared. A *z* score greater than zero indicates relative overestimation of length, whereas a *z* score less than zero indicates underestimation.

Finally, to determine whether or not subjects crossed-over on the line bisection task, we examined the proportion of ipsilesional versus contralesional bisections for each line length using the *binomial test*. This is a conservative measure of the crossover effect.

RESULTS

Symptoms of neglect were more prevalent among patients with RHL than LHL (Table 1). The exponents for RHL patients were significantly less than 1 for both line length estimation [95% confidence intervals (c.i.) = .86–.96] and line bisection (c.i. = .91–.97), and the constants were greater than 1 for line bisection (c.i. = 1.05–1.56) and length estimation (c.i. = 1.03–1.16). In contrast, exponents for the LHL patients were not different from 1 for either task (c.i. = .95–1.02 for line length estimation and .96–1.00 for line bisection) nor were the constants greater than 1 (c.i. = .95–1.3 for line bisection and .99–1.11 for length estimation).

ANOVA yielded a significant effect of group on the exponent such that RHL patients had lower exponents than LHL patients, [$F(1,10) = 7.7$, $p < .019$]. There was no significant effect of task on the exponent, $p = .15$, nor was was there a significant Group × Task interaction, $p = .35$. There was no effect of group on the constant, $p = .26$, nor was the task, $p = .07$, or Group × Task interaction significant, $p = .59$.

Data plots show that both groups of subjects generally overestimated the length of short lines and underestimated long lines in each task with the exception that LHL patients were more accurate when estimating lines longer than 15 cm and bisecting lines longer than 5 cm. Figure 2 shows length estimation data for all lines; Figures 3a and b show length estimation data for comparable line lengths in the estimation and bisection tests.

Regarding the crossover effect on line bisection, both groups of subjects made significantly more ipsilesional than contralesional errors on long lines and more contralesional than ipsilesional errors on short lines (Figure 4: bar graph). In other words, patients with RHL crossed over from right to left, whereas patients with LHL crossed over from left to right. The line graph in Figure 4 depicts length estimation error. It can be seen that contralesional bisection errors correspond with overestimates of line length, whereas ipsilesional errors correspond with underestimates of line length.

DISCUSSION

The data provide varying degrees of support for the orientation/estimation hypothesis of crossover. Consistent with our predictions, both the RHL and LHL patients generally underestimated the length of long lines and overesti-

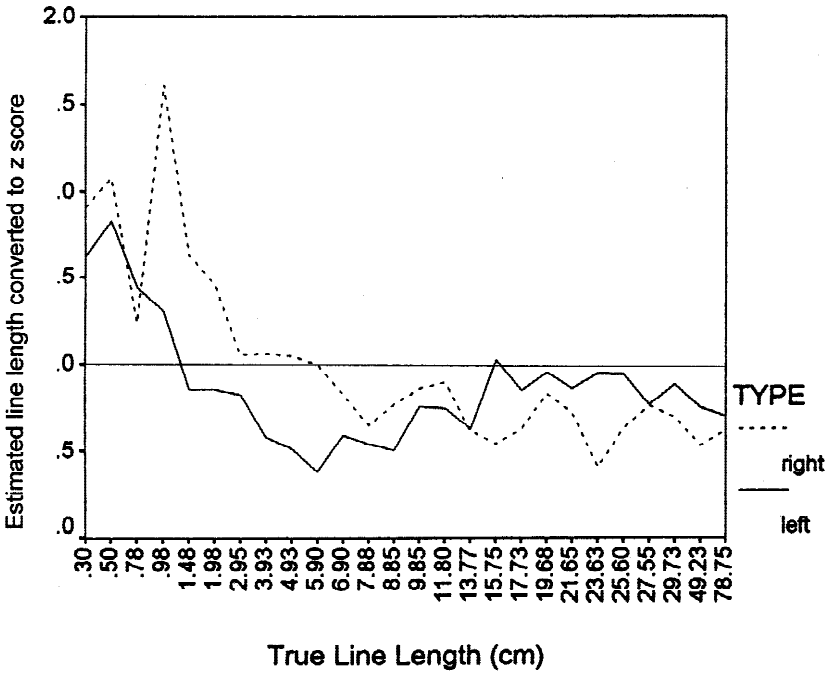


Fig. 2. Data for all 26 line lengths in the length estimation task. A *z* score greater than zero indicates overestimation of line length, whereas a *z* score less than zero indicates underestimation. It can be seen that both groups of subjects overestimated the length of the short lines and underestimated the length of long lines.

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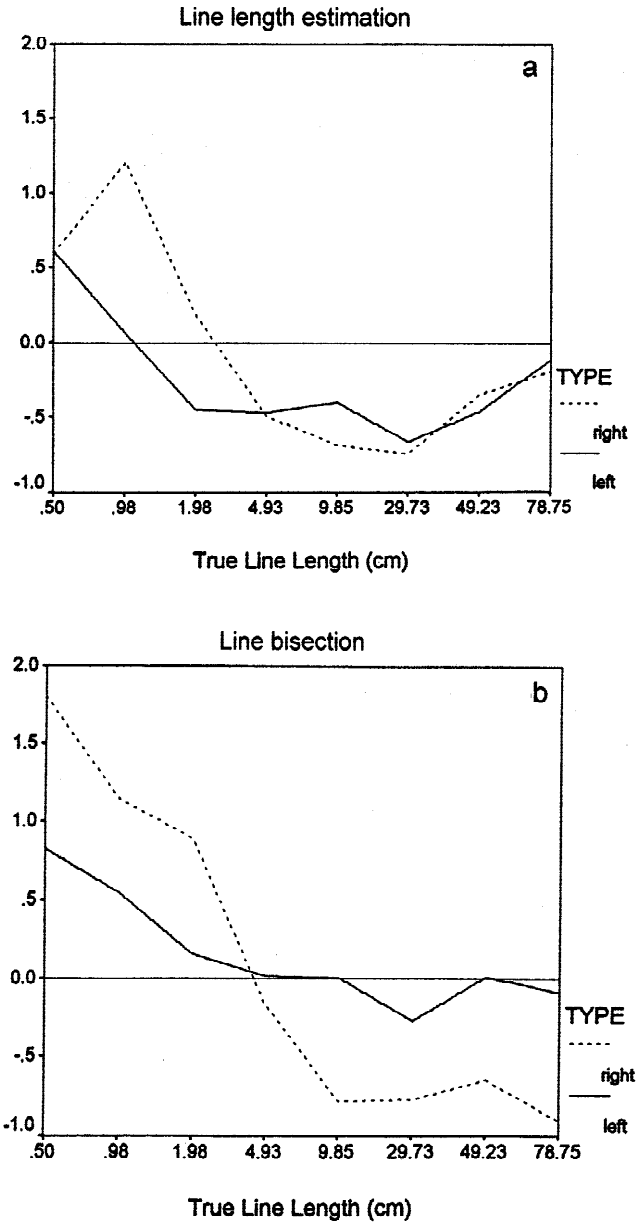


Fig. 3. Comparison of the perceived total length of each line as inferred from the length estimation (Graph 3a) and line bisection tests (Graph 3b). Total line length was inferred from bisection by multiplying the distance between the bisection mark and the ipsilesional end of the line by 2. As in Figure 1, a *z* score greater than zero indicates overestimation of line length whereas a *z* score less than zero indicates underestimation. The two figures show a similar pattern of overestimating short lines and underestimating long lines regardless of whether the total line length was derived from visual inspection or bisection.

mated short lines upon direct magnitude estimation, and the two groups crossed-over in opposite directions on the line bisection test. Neglect was associated with lower power function exponents in both tasks. However, one limitation of the study is that only the RHL patients tended to have multiple symptoms of neglect, so it cannot be determined precisely whether or not a lower exponent relates to neglect, right hemisphere injury, or both. Other studies have shown a negative correlation between neglect severity and the size of the exponent (Chatterjee et al., 1994a), as well as a relationship between neglect and magnitude estimation that is independent of lesion laterality (Mennemeier et al., 1998). Therefore, we suspect that the brain damage associated with neglect was critical in lowering the power function exponent for RHL patients in this study, but we acknowledge, as well, that lesion laterality may also influence magnitude estimation (Mennemeier et al., 1998).

Results for the length estimation and bisection tests were consistent although not exactly parallel. There was no statistical difference in the size of exponent between tasks suggesting that the two tasks both depend on a similar cognitive operation. However, the size of the exponents were consistently lower in the length estimation than in the bisection task among RHL patients. This result may be viewed as a task difference. The data plots in Figure 3 show a tighter association between true and estimated lengths for the bisection than the estimation test, and R^2 values in Table 1 were also consistently higher for the bisection task suggesting a better fit of the regression line. Therefore, bisection may constrain errors to a greater degree than length estimation even though the general pattern is the same (underestimation of long lines and overestimation of short lines). Length estimation is performed without a modulus, a reference or standard for judgement, whereas the line itself serves as a modulus in every trial of line bisection. This task difference could explain a lower exponent for the estimation test among RHL patients. Alternatively, a lower exponent in the length estimation than bisection test could relate to the fact that bisection involves motor systems to a greater degree than length estimation based on visual inspection. The form of the power function may be altered as patients with neglect convert sensory percepts into corresponding motor acts. Also consistent with the hypothesis that length estimation and bisection depend on a similar cognitive operation is the fact that in every case where a significant contralesional error was observed on line bisection, subjects overestimated the corresponding line length upon direct magnitude estimation. Conversely, in every case where a significant ipsilesional error was observed on line bisection, subjects underestimated the corresponding line length. The convergence of length estimation and bisection data in both subject groups supports the hypothesis that bisection performance can be explained in terms of magnitude estimation.

The exponents for LHL patients were not different from one, which makes them similar to normal subjects. In traditional psychophysical studies of line length estimation (Hollingworth, 1909), normal subjects consistently overestimate short lines and underestimate long lines, but their exponents are not statistically different from one (Stevens & Galanter, 1957). Left hemisphere lesioned patients are also similar to normal subjects in that both groups tend to be more accurate when estimating long rather than short lines (Mennemeier et al., 1998, 1999). Again, because most

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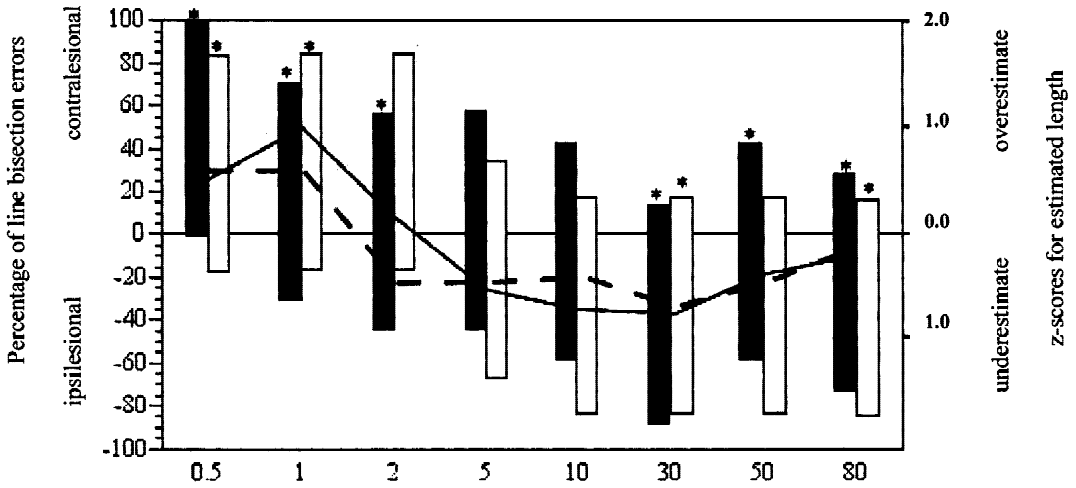


Fig. 4. Bar and line graphs showing the convergence of data from the line bisection and length estimation tests. Bar graphs show the percentage of lines (*y*-axis, left side of graph) bisected on the contra- and ipsilesional side of true center for both right (white bars) and left (black bars) hemisphere lesioned patients. Asterisks indicate a significant bias in one direction at the $p < .05$ level–Binomial Test. Line graphs show length estimation data in z-scores (y-axis, right side of graph) for right (solid line) and left (dashed line) hemisphere lesioned patients. It can be seen that in every case where lines were bisected significantly to the contralateral side of true center, the corresponding line lengths were overestimated upon visual inspection in the length estimation test. Further, in every case where lines were bisected significantly to the ipsilesional side of true center, the corresponding line length was underestimated in the length estimation test.

of the RHL patients had neglect and most LHL patients did not, it is difficult to determine if these findings indicate a specialization of the right cerebral hemisphere for magnitude estimation, a specific relationship between neglect and bias in magnitude estimation, or both. We have speculated elsewhere (Mennemeier et al., 1998) that the right hemisphere may estimate both small and large stimuli, whereas the left may only estimate small stimuli. Regardless, the demonstration of a crossover effect among LHL patients who do not have neglect refutes the notion that crossover relates specifically to the pathophysiology of neglect.

One reviewer pointed out that the data presented in Figures 2 and 3 are not exactly linear as long lines are bisected more accurately than short lines. He or she questioned whether this nonlinearity contradicts one of the main hypotheses of the study—that short lines are overestimated and long lines underestimated. In fact, that the non-log-transformed data in Figures 2 and 3 are not exactly linear merely underscores one of the main points of this study—that crossover stems from normally occurring bias in magnitude estimation. Psychophysical studies are consistent in showing that perceived stimulus intensity is a power function of physical intensity (a log–log relationship), not a linear function (Stevens and Galanter, 1957). Log-transforming the data in Figures 2 and 3 does result in a nearly perfect linear fit of the data as demonstrated by the high R^2 values observed in Table 1.

Whereas the findings for our RHL patients are consistent with earlier explanations of the crossover effect (Chatterjee, 1995; Marshall & Halligan, 1989; Marshall et al., 1998; Mozer et al., 1997; Tegner & Levander, 1991), those for the LHL patients suggest that an alternative explanation is warranted. Tegner and Levander (1991) proposed two independent mechanisms to explain crossover, a leftward pushing mechanism on short lines such as perceptual completion and a rightward pushing mechanism on long lines such as ipsilesional hyperattraction. Chatterjee (1995) viewed the underestimation of long words and overestimation of short words as different parts of the same continuous function (i.e., a power function). He explained crossover in terms of disinhibition of leftward confabulatory mental representations within the context of a rightwardly constricted attentional window. Marshall et al. (1998) explained crossover as unbridled contextual effects among patients with neglect. While each of these hypotheses may account for the systematic magnitude estimation errors among RHL patients with neglect, they would not predict the same pattern of errors among LHL patients without neglect. Additionally, the hypothesis of Marshall and Halligan (1989) and Mozer et al. (1997) that crossover bisections on short lines result from the adoption of a "normal" left-to-right scan path cannot account for direction of crossover observed among LHL patients in this study.

As the crossover effect can be readily observed in normal subjects (McCourt & Jewell, 1999; Mennemeier et al., 1998, 1999), and as it has now been shown among LHL patients, we see no need for an explanation that is predicated on neglect pathophysiology. We think the orientation/estimation hypothesis has several advantages over other explanations. Because it is based on normally occurring biases in attentional orientation and magnitude estimation, the hypothesis serves to demystify certain aspects of neglect behavior by

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asserting that normal cognitive processes are only accentuated in cases of neglect. For example, if crossover is a normal phenomenon, then it need not be a "repressed pain in the neck" for neglect theorists because it is not a consequence of neglect, *per se*. Additionally, the fact that neglect (or perhaps right hemisphere injury) accentuates errors in length estimation may provide a useful clue as to the cortical mechanisms that normally mediate magnitude estimation, which presently are not well understood. As noted by Chatterjee et al. (1994a), Stevens (1970) attributed magnitude estimation phenomena to biologic properties of the peripheral nervous system (i.e., sensory–neural transduction), but data such as these clearly implicate a cortical contribution.

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