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Line Bisection in the Split Brain

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The authors examined line bisection in 4 patients with resection of the corpus callosum and in 22 control participants. The control participants showed a leftward bias, especially with the left hand, implying right-hemispheric dominance in spatial attention. Two patients with anterior callosotomy showed similar biases, suggesting that the anterior callosum plays only a small role. A patient with complete callosotomy showed a strong right bias, regardless of hand use. A patient with posterior callosotomy showed the opposite pattern: a strong left bias, regardless of hand use. These data suggest that the posterior corpus callosum normally plays a role in line bisection and that the resection of the posterior corpus callosum produces consistent bias. The direction of the bias depends on which hemisphere assumes control.

The line-bisection task is widely used to investigate spatial attention. Patients with right-hemispheric lesions deviate to the right of the objective middle when bisecting lines—a phenomenon that has been called *left hemineglect*—whereas normal right-handed people tend to systematically bisect lines to the left of the objective middle, called *right pseudoneglect*. This suggests that although the right hemisphere is dominant in spatial attention and can direct attention to both sides of space, it slightly favors left hemispace, producing a marginal tendency to neglect the right (Bradshaw, Bradshaw, Nathan, Nettleton, & Wilson, 1986).

However, there is evidence that the line-bisection task can also be used to investigate callosal functions when the effect of hand use is taken into account. Several studies (Brodie & Pettigrew, 1996; Hausmann, Ergun, Yazgan, & Güntürkün, 2002; Luh, 1995; Hausmann, Waldie, & Corballis, 2003; Scarisbrick, Tweedy, & Kuslansky, 1987; for a review, see Jewell & McCourt, 2000) have shown that pseudoneglect in normal participants is especially pronounced when the left hand is used to bisect the lines. Because each hand is controlled primarily by the contralateral hemisphere, this may again reflect the dominance of the right hemisphere. Nevertheless, right pseudoneglect persists, albeit reduced, when the right hand is used, which implies interhemispheric transfer of the attention-biased perceptual representations from the right hemisphere to the motor cortex of the left hemisphere. This transfer presumably involves the corpus callosum.

There is also indirect evidence that the effect of hand use on line bisection may depend on the size of the corpus callosum or on the size of its subdivisions. For example, in one study, women showed similar degrees of left bias with either hand, whereas men showed the bias predominantly with the left hand (Hausmann et al., 2002). This might reflect stronger interhemispheric connectivity in women, whose posterior corpus callosums are larger, on average, than those in men (DeLacoste-Utamsing & Holloway, 1982; Holloway, Anderson, Defendini, & Harper, 1993; Oka et al., 1999; Steinmetz et al., 1992; for review, see Driesen & Raz, 1995). Moreover, young children show symmetrical neglect, with the left hand showing a left bias and the right hand a right bias, but the effect of hand decreases with age so that the left bias is present for both hands by around puberty (Bradshaw, Spataro, Harris, Nettleton, & Bradshaw, 1988; Dobler et al., 2001; Hausmann et al., 2003; Roeltgen & Roeltgen, 1989). This may reflect maturation of the corpus callosum. Although the number of callosal fibers reaches its maximum in utero (LaMantia & Rakic, 1984), quantitative magnetic resonance imaging (MRI) has shown that the total midsagittal callosal area increases in size up to the age of 18 years, particularly in the regions of the midbody and splenium (Giedd et al., 1996).

The role of the corpus callosum in line bisection is more directly supported by studies of patients with callosal infarction and partial or complete commissurotomy. Kashiwagi, Kashiwagi, Nishikawa, Tanabe, and Okuda (1990) reported left hemineglect in a patient with callosal infarction in the trunk and genu of the corpus callosum, with rightward errors in line bisection, but only when the right hand was used. A more symmetrical effect of hand, with the left hand showing a significant left bias and the right hand a significant right bias, was reported by Heilman, Bowers, and Watson (1984) in a 43-year-old right-handed woman with a hemorrhage in the region of the corpus callosum, extending from the genu to the splenium. Computerized tomography

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scans showed the most anterior extent of the infarction at the junction of the genu and the body. The posterior one fourth to one fifth of the body and all of the splenium were intact.

Goldenberg (1986) investigated a 46-year-old right-handed woman who suffered destruction of the anterior two thirds of the corpus callosum because of pericallosal hemorrhage and ischemia. Like the patients described by Kashiwagi et al. (1990) and Heilman et al. (1984), she showed some evidence of symmetrical neglect in line bisection, but this was dependent on the position of the line. The right hand showed a right bias only when the line itself was in left hemispace or in the center but not when it was in right hemispace. The left hand showed a left bias in all line positions, but it was greatest in right hemispace. Goldenberg concluded that some callosal transfer of visual information was possible but may have been degraded.

These studies suggest that partial callosal infarction or partial commissurotomy may result in some regression toward symmetrical neglect, with the right hand showing a right bias and the left hand a left bias. This is similar to the symmetrical neglect shown by young children whose corpus callosums have not yet matured. Insofar as the neglect is fully symmetrical, with equal and opposite biases, it suggests that the asymmetry of spatial attention between the hemispheres may also depend on maturation. It is possible, for example, that the left hemisphere is prevented from developing ipsilateral as well as contralateral spatial awareness, comparable with that in the right hemisphere, by the development of competing language representations in the parietotemporal cortex.

Somewhat more complex findings have been reported in patients with complete forebrain commissurotomy. Plourde and Sperry (1984) found that 3 such patients all failed to show overall unilateral neglect on a rod-bisection task, although they made substantial errors. Nevertheless, there were some systematic biases, depending on the hand used and the location of the rod. With the left hand, 2 of the patients (N.G. and L.B.) erred more to the left (N.G. always). When using the right hand, and when the rods were presented in the center or in left hemispace, both of these patients erred to the right. This pattern indicated some degree of symmetrical neglect. The 3rd patient of this study (R.Y.) showed a robust bias to the right, indicating a left-sided neglect, but somewhat paradoxically this occurred only when the left hand was used. A control group of right-handed patients who had sustained right-hemisphere damage showed typical left unilateral neglect. Although 1 of the patients (L.B.) tested by Plourde and Sperry did not show consistent neglect, he did show evidence of left neglect under more stringent conditions. When asked to judge whether horizontal lines, flashed for 100 ms, extended further to the left or right of a central fixation mark, he showed a strong bias to judge the right side longer (Corballis, 1995). Control participants were slightly biased toward the left, which is consistent with right pseudoneglect.

In the present study, we examined visual line bisection in 4 patients—1 with complete callosotomy, 2 with anterior callosotomy, and 1 with posterior callosotomy. None had been previously tested on line bisection, and, to our knowledge, there has been no previous report on line bisection in a patient with posterior callosotomy. Because the position of the lines (left, center, or right) had an important influence on the results in previous studies (Hausmann et al., 2002; Heilman et al., 1984; Luh, 1995; Plourde & Sperry, 1984; for review, see Jewell & McCourt, 2000), we included line position as a variable in the experiment. By using the same task for all 4 patients, we hoped to gain clearer insight into the role of the different regions of the corpus callosum in the integration of spatial attention.

Method

Participants

Four right-handed patients with varying degrees and locations of callosal section, carried out for the relief of epilepsy, were the main focus of the study. One (D.D.V.) had undergone complete callosotomy, whereas the other 3 (M.C., L.P., and R.V.) had undergone partial callosotomies. MRI scans of D.D.V., L.P., and R.V., showing the extent of callosal sections, are available in Fabri et al. (1999), and scans showing the extent of callosal section in M.C. are available in Aglioti et al. (2001) and Fabri et al. (2001). There were also 22 neurologically normal control participants.

D.D.V. is a 38-year-old man with complete callosotomy. He had his second operation, which completed the callosotomy, in 1994 (for more information, see Fabri et al., 1999).

M.C. is a 42-year-old man who developed severe idiopathic epilepsy at 12 years old. Because of unsuccessful pharmacological treatments, he underwent partial callosotomy in 1998, followed a year later by an extension of the section up to and including the splenium. MRI examinations following the second operation show that most of the corpus callosum, sparing only the genu and rostrum, has been transsected (Aglioti et al., 2001; Fabri et al., 2001).

L.P. is a 27-year-old woman with an anterior callosotomy. She was operated on in 1994. Although the borders between the splenium and the body of the corpus callosum are not clearly identifiable anatomically (e.g., Geffen, Nilsson, & Quinn, 1985), MRI scans show that a part of the posterior body and all of the splenium were spared (Fabri et al., 1999).

R.V. is a 32-year-old man who underwent anterior callosotomy when he was 19 years old. In contrast to L.P., he has only a small portion of the splenium intact (Fabri et al., 1999).

All patients were right-handed according to the Edinburgh Handedness Inventory (Oldfield, 1971). The laterality quotient (LQ) provided by this test is calculated as $[(R - L)/(R + L)] \times'$ 100, resulting in values between 100 and -100. Positive values indicate dextrality, and negative values indicate sinistrality. The LQ was 100 for D.D.V., 90 for M.C., 100 for L.P., and 50 for R.V. According to his father, R.V. was left-handed until the age of 8 years. All patients were chronically treated with antiepileptic medication. They were tested in Ancona, Italy, in March 2002.

The control group was composed of 11 men and 11 women. Their mean ages were 34.91 years (SD = 11.09; range = 21–58 years) for the men and 29.63 years (SD = 6.90; range = 22–41 years) for the women. The mean LQ of the men was 86.44 (SD = 15.02; range = 60–100) and that of the women was 89.72 (SD = 20.51; range = 30–100). The reading direction of all participants was left to right. Those who had used any medication affecting the central nervous system during the past 6 months were excluded. All participants had normal or corrected-to-normal visual acuity and were naive to the study's hypothesis.

Procedure and Materials

The line-bisection task was identical to that used in a previous study (Hausmann et al., 2002, 2003). It was composed of 17 horizontal black lines 1 mm wide on a white sheet of paper (21 cm × 30 cm). The lines ranged from 100 to 260 mm in length in steps of 20 mm. The mean length was 183.5 mm. They were pseudorandomly positioned so that seven lines appeared in the middle of the sheet, five lines appeared near the left margin, and five lines appeared near the right margin. The lateralized lines were 13 mm away from the margin. The line lengths for the seven centered lines were 12 cm (one line), 18 cm (two lines), 22 cm (two lines), 24 cm (two lines; $M = 20$ cm) and 10 cm, 14 cm, 16 cm, 20 cm, and 26 cm ($M = 17.2$ cm) for the five left- and five right-lateralized lines, respectively. The sheet was laid in front of the participant's midline. Participants were instructed to bisect all lines into two parts of equal length by marking the subjective midpoint of each line with a fine pencil. All participants completed the task with one hand and then repeated it with the other in a balanced order. The experimenter covered each line after it was marked to ensure that the participants were not biased by their previous choices. There were no time restrictions. The deviations to the left or to the right of each marked line were carefully measured to 0.5 mm accuracy. The percentage deviation score for each line was computed as follows: [(measured left half – true half)/true half] × 100. This measure is comparable with that used in other studies (Scarisbrick et al., 1987; Shuren, Wertman, & Heilman, 1994) and takes individual line length into account. We then computed the mean score for all lines separately for each hand used. Negative values indicate a left bias, and positive values indicate a right bias.

Results

Control Participants

The percentage deviation scores of the control participants were subjected to a 2 × 3 × 2 analysis of variance (ANOVA), with hand (left hand, right hand) and line position (left, center, right) as within-subject factors and gender as a between-subjects factor. Descriptive statistics are shown in Table 1.

As expected, there was an overall leftward bias, which was indicated by a significant intercept, $F(1, 20) = 4.98$, $p < .05$, $MSE = 29.34$. The leftward bias was significantly more pronounced when the left rather than the right hand was used, $F(1, 20) = 15.52$, $p < .001$, $MSE = 11.74$. A significant main effect of line position, $F(2, 40) = 7.56$, $p < .01$, $MSE = 3.56$, showed that the bias was less pronounced when the lines were positioned to the right (-0.17 ± 0.51) relative to both the center (-1.66 ± 0.50), $t(21) = 6.21$, $p < .001$, and the left (-1.33 ± 57), $t(21) = 2.29$, $p < .05$, of the page. Neither the main effect of gender nor any other interaction was significant (all Fs < 1.59, *ns*). Because of the nonsignificant effects of gender, the data of men and women were combined in all remaining analyses.

Split-Brain Patients

In order to compare the individual data of each callosotomized patient with those of the control participants, we treated each as a separate group, with error terms taken from analysis of the control participants. Descriptive statistics for the callosotomized patients are shown in Table 2 and in Figure 1.

D.D.V. (full callosotomy) differed significantly from control participants with respect to the overall bias, $F(1, 21) = 15.21$, $p < .001$, showing a strong right bias of 7.56 in contrast to the left bias of –1.05 in control participants. Although he showed a right bias with both hands, the right bias was particularly pronounced with the right hand. The right bias for the left hand was shifted to the left, relative to right hand performance. Although this hand-use effect exceeded that of the control group, the interaction of hand with group just failed to reach significance, $F(1, 21) = 4.21$, $p = .053$. Line position, however, interacted strongly with group, $F(2, 42) = 154.41$, $p < .001$. In contrast to the control participants, who showed a significant reduced left bias when lines were positioned to the right (compared with center and left), D.D.V. showed a strong left bias of –10.74 when lines were located to the right, a right bias of 12.19 when the lines were located in the center, and an even stronger right bias of 21.23 when they were located to the left.

R.V. (anterior callosotomy) did not significantly differ from control participants in overall bias, $F(1, 21) = 0.06$, *ns*. However, the effect of hand differed significantly from that of control participants, $F(1, 21) = 5.18$, $p < .05$, reflecting a pattern of a "symmetrical neglect," a left bias of –4.86 with the left hand and a right bias of 3.87 with the right hand. The interaction between line position and group was also significant, $F(2, 42) = 14.72$, $p < .01$. R.V.'s pattern was similar to that of D.D.V.—he showed a strong left bias of –4.02 when lines were located to the right,

Table 1
Relative Directional Deviations (%) and Standard Errors (in Parentheses) for Visual Line Bisection as a Function of Hand Used, Line Position, and Gender in Control Participants

	Men (n = 11)		Women (n = 11)		All (N = 22)	
Line position	Left hand	Right hand	Left hand	Right hand	Left hand	Right hand
Left	−1.74 (0.87)	0.08 (1.22)	−3.24 (0.87)	−0.42 (1.22)	−2.49 (0.61)	−0.17 (0.86)
Center	−2.75 (0.73)	−0.81 (0.83)	−2.77 (0.73)	−0.31 (0.83)	−2.76 (0.52)	−0.56 (0.59)
Right	−1.63 (0.89)	1.03 (0.78)	−1.24 (0.89)	1.16 (0.77)	−1.43 (0.63)	1.09 (0.55)
All	−2.04 (0.74)	0.10 (0.83)	−2.42 (0.74)	0.15 (0.83)	−2.23 (0.53)	0.12 (0.59)

Note. Negative values indicate a deviation to the left; positive values indicate a deviation to the right.

Table 2
Relative Directional Deviations (%) for Visual Line Bisection as a Function of Hand Used and Line Position in 4 Patients With Complete, Anterior, and Posterior Resections of the Corpus Callosum

	D.D.V. (complete)		R.V. (anterior)		L.P. (anterior)		M.C. (posterior)	
Line position	Left hand	Right hand	Left hand	Right hand	Left hand	Right hand	Left hand	Right hand
Left	15.53	26.93	1.47	8.76	−5.14	9.61	13.08	−11.28
Center	8.27	16.10	−6.66	1.50	−8.06	−6.52	−6.88	−17.10
Right	−13.26	−8.21	−9.38	1.34	−9.00	−2.92	−22.86	−27.59
All	3.51	11.06	−4.86	3.87	−7.40	−0.57	−5.55	−18.66

Note. Negative values indicate a deviation to the left; positive values indicate a deviation to the right.

which was reduced to –2.58 when lines were located in the center. When lines were to the left, he showed a strong bias of 5.12 to the right.

L.P. (anterior callosotomy) also did not differ significantly from control participants in overall bias, $F(1, 21) = 1.41$, *ns*. The effect of hand differed only marginally from that of control participants, $F(1, 21) = 3.33$, $p = .08$. The interaction between line position and group was again significant, $F(2, 42) = 15.10$, $p < .001$, revealing an effect of line position in L.P. similar to that in R.V. However, the significant three-way interaction between line position, hand, and group, $F(2, 42) = 8.39$, $p < .01$, indicates that the Group × Line Position interaction was especially pronounced when L.P. used the right hand. L.P., like the control participants, showed a consistent left bias when the left hand was used, regardless of line position.

M.C. (posterior callosotomy) showed a pattern of results very different from those of the 3 other patients and the control participants. Each comparison between M.C. and the control participants was significant. His left bias of –12.11 was clearly greater than the bias of –1.05 shown by the control participants, $F(1, 21) = 25.06$, $p < .001$. The effect of hand also differed significantly from that of control participants, $F(1, 21) = 30.45$, $p < .001$, and was in the opposite direction of what has been typically found. His left bias of –18.66 with the right hand was more than triple the left bias of –5.55 with the left hand. When measured relative to the bias with the right hand, all other patients and control participants showed a bias to the left with the left hand (see Figure 2). This was true also of D.D.V., even though he showed a right bias with both hands. The interaction between line position and group was significant, $F(2, 42) = 97.59$, $p < .001$, and the significant three-way interaction between line position, hand, and group, $F(2, 42) = 19.02$, $p < .001$, indicates that, in contrast to L.P.'s results, the effect of the Line Position × Group interaction

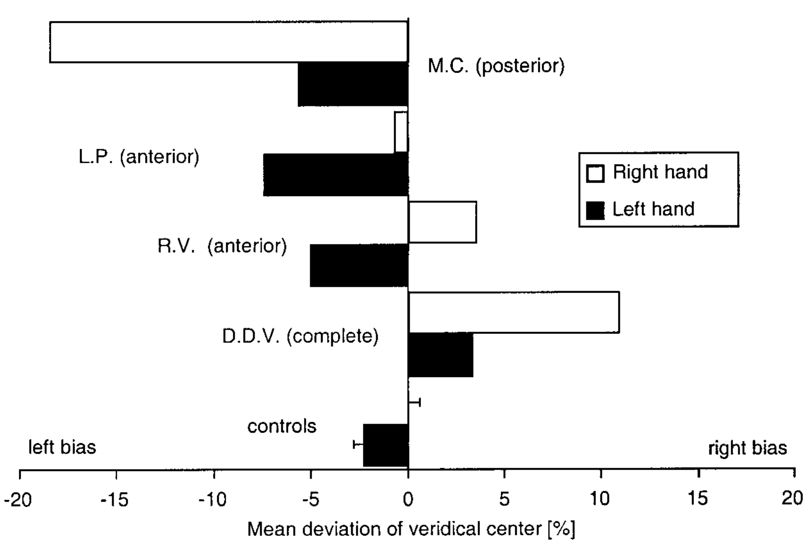

Figure 1. Mean deviation from the true center in line bisection according to hand use in 4 commissurotomized patients with complete (D.D.V.), anterior (R.V., L.P.), and posterior (M.C.) resections of the corpus callosum as well as in control participants. Negative values indicate a bias to the left, and positive values indicate a bias to the right of the objective middle. Error bars represent standard errors of the means.

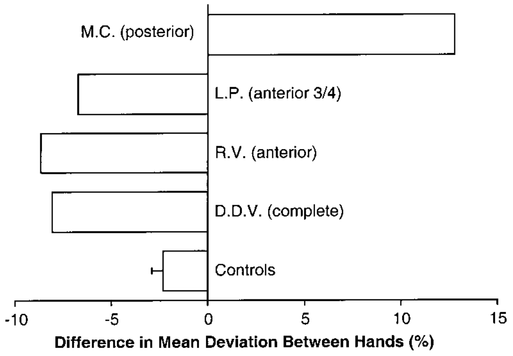

Figure 2. Differences between hands in mean deviations from the true center in line bisection in 4 commissurotomized patients with complete (D.D.V.), anterior (R.V., L.P.), and posterior (M.C.) resections of the corpus callosum as well as in control participants. Negative values indicate a left-hand bias to the left, relative to the right-hand bias. Positive values indicate a left-hand bias to the right, relative to the right-hand bias. Error bars represent standard errors of the means

was especially pronounced when the left hand was used. M.C. showed a more consistent left bias for the different line positions when the right hand was used.

Discussion

Overall, the left bias that is typically observed in neurologically normal individuals was also found in the control group and in the 3 patients with partial callosotomy. The bias was stronger than normal in M.C., who had a resection of the posterior callosum (sparing only the genu and rostrum), whereas in the 2 patients with anterior callosotomy, R.V. and L.P., the bias did not differ significantly from that of the control participants.

These two cases differed, however, with respect to the effect of hand. R.V. showed a left bias with the left hand and a right bias with the right hand, whereas L.P. showed a left bias with both hands that was stronger with the left hand than with the right hand. In the case of R.V., then, the bias is more symmetrical and comparable with that previously shown in patients with callosal infarction in, or in a section of, anterior regions of the corpus callosum (Goldenberg, 1986; Heilman et al., 1984; Kashiwagi et al., 1990). It is also similar to the pattern observed in neurological normal young children, who also show symmetrical neglect attributable to callosal immaturity (Bradshaw et al., 1988; Dobler et al., 2001; Hausmann et al., 2003; Roeltgen & Roeltgen, 1989). In the case of L.P., the pattern is closer to that seen in normal adults. The difference between the 2 patients can be attributed to the amount of posterior corpus callosum remaining after the surgery. In R.V., only a small portion of the splenium was spared, so there was relatively little transfer of attention-dependent information, and neglect was a function of the hemisphere controlling the hand. In L.P., by contrast, the posterior body and splenium were clearly spared, enabling the right hemisphere to play a role regardless of the hand used.

Taken together, the results from these 2 patients suggest that the anterior region of the corpus callosum has little involvement in line bisection and spatial attention. Rather, the interhemispheric transfer needed for accurate comparison of the two sides of space depends on the posterior region, and probably mainly on the splenium. This is also supported by the fact that the splenium connects the posterior tempoparietal regions of the cortex, and it is damage to these areas that typically results in hemineglect.

However, Arguin et al. (2000) found an involvement of the anterior corpus callosum in another type of visuospatial task. To investigate the interhemispheric integration of the visuospatial attention system in patients with anterior or total callosotomy, Arguin et al. had participants produce simple reactions to visual targets shown in the left or right visual fields, which were predicted by valid, ambiguous, neutral, or invalid cues. In contrast to control participants, the majority of split-brain patients with total or anterior callosal section were capable of orienting their visual attention to both hemifields simultaneously. This suggests that the anterior corpus callosum might play a crucial role in the functional integration of visuospatial attention between hemispheres. Although the parietal lobes appear to be the main cortical center for the control of visuospatial attention, patients with anterior callosal sections showed evidence for the same dual visuospatial attention system as patients with total callosotomy. Evidence for a dual visuospatial attention system in the split-brain patients of this study was obtained only from R.V. This patient's symmetrical neglect, a left bias with the left hand and a right bias with the right hand, makes it likely that each hand was controlled by its own visuospatial attention system within the contralateral hemisphere. However, other studies (e.g., Holtzman, Sidtis, Volpe, Wilson, & Gazzaniga, 1981; Reuter-Lorenz & Fendrich, 1990), as well as the line-bisection errors of the remaining 3 split-brain patients of this study, suggest that a section of the anterior portion of the corpus callosum has little or no effect on the interhemispheric transfer of visuospatial information. Properties of the task (e.g., required processing time) might be responsible for the inconsistency in the literature (see also Arguin et al., 2000).

If the splenium is critical for accurately comparing the two sides of space, as shown by the study presented here, this can explain why both M.C., with section of the splenium, and D.D.V., with section of the entire corpus callosum, showed stronger and more consistent biases than the other 2 patients, which is more consistent with true hemineglect than with pseudoneglect or symmetrical neglect. In the case of D.D.V., there was a strong overall right bias, regardless of hand. This is consistent with left hemineglect, similar to that observed in patients with right lesions of the posterior temporoparietal regions and suggests that performance was largely under the control of the left hemisphere. It should be noted, however, that 2 of the commissurotomized patients studied by Plourde and Sperry (1984) did not show consistent neglect in rod-bisection, although they did show large deviations on individual trials, suggesting that the controlling hemisphere may have fluctuated, although influenced by the hand used. The 3rd patient studied by Plourde and Sperry did show evidence of left neglect when using his left hand.

There is some evidence that D.D.V. may be unusual among callosotomized patients in showing a marked dependence on the left hemisphere in visual tasks. In an unpublished experiment (M. C. Corballis, personal communication, May 10, 2002), he was unusually poor at responding to flashes of light in the left visual field in a simple reaction-time task. He responded to only 1 of 50 light flashes in the left visual field when responding with his right hand and to only 13 of 60 in the left visual field when he used his left hand. He had little difficulty responding to right-visual-field flashes with either hand and was much faster at responding to flashes in both fields than at responding to flashes in either field, indicating that flashes in the left visual field were at least registered. His poor detection of single left-visual-field flashes contrasts with the performance of other callosotomized patients, who have little difficulty with this task (e.g., Berlucchi, Aglioti, Marzi, & Tassinari, 1995; Corballis, 1998; Iacoboni & Zaidel, 1995) and suggests that D.D.V. is unusually dominated by the left hemisphere, even when using his left hand.

M.C., the patient with posterior section of the corpus callosum, showed a strong overall left bias of more than 12%, implying right neglect. Although this is consistent with control by one hemisphere, implying a lack of spatial integration, it is not clear why his neglect was in the opposite direction to that shown by D.D.V., or why the neglect should have been so marked. Right neglect implies control by the right hemisphere, and if this hemisphere can direct attention to both sides of space, as Heilman and others have argued (e.g., Heilman & Valenstein, 1979; Heilman & Van Den Abell, 1980; Mesulam, 1981), then M.C. should have displayed only a mild left bias, consistent with the pseudoneglect shown by normals. It is possible that M.C. shows a reversal of the usual asymmetry, such that his left hemisphere is dominant for spatial attention. The overall left bias, and the effects of the hand used and of line position, are all consistent with the possibility that his line-bisection performance was controlled by a right hemisphere capable of directing attention only (or primarily) to the left side. To our knowledge, M.C. is the first patient with posterior callosal section to have been tested on line bisection, and it would be interesting to discover whether other patients with posterior section also show a pronounced left bias.

A strong influence of sections of the posterior corpus callosum, which connects the parietal lobes, supports the idea that the right parietal lobe appears to be the main cortical center for the control of visuospatial attention and, thus, that the line-bisection bias appears to be mainly perceptual in origin. However, the line-bisection task used in this study cannot differentiate between the influence of perceptual and motor factors on the directional bias. The left bias in control participants is at least partially perceptual in nature, but a motor-orienting bias may also play a role (Milner, Brechmann, & Pagliarini, 1992). This assumption is supported by hand-use effects in line bisection (e.g., Brodie & Pettigrew, 1996; Hausmann et al., 2002; Scarisbrick et al., 1987) because purely perceptual factors would not be expected to be altered by hand usage (Luh, 1995). The idea that the line-bisection errors arise from motor rather than a perceptual bias is also supported by brain-damaged patients with hemispatial hypokinesia. Luh (1995) suggested that the left-hand usage may activate right-hemisphere premotor mechanisms, which might result in an increased bias on line bisection, and she concluded that either motor or perceptual asymmetries may underlie the hemispatial effect. More direct evidence that motor factors play an important role comes from Bisiach, Geminiani, Berti, and Rusconi (1990), who used a line-bisection task that allowed uncoupling of the direction of visual attention from that of hand movement and thus made it possible to isolate and separately assess perceptual and premotor factors. Using this task, the line-bisection bias suggests that premotor factors were more pronounced in patients with lesions involving the frontal lobes than in patients with lesions confined to postrolandic areas (Bisiach et al., 1990). If premotor factors are more pronounced in patients with frontal lesions, then it is possible that patients with an anterior section of the corpus callosum might show a bisection error that is more influenced by motor factors, whereas patients with a posterior section of the corpus callosum might show an attentional bias that is more perceptually based. R.V., with an anterior callosotomy, showed symmetrical neglect, a bias that differed as a function of hand use. However, R.V.'s overall bias did not significantly differ from that of control participants. In contrast, M.C., with posterior resection of the corpus callosum and D.D.V., with total callosotomy, showed, in addition, an overall bias that differed significantly from control participants. This might indicate that patients with total or posterior resection of the corpus callosum show a stimulus-based neglect that consists of motor and perceptual components, whereas split-brain patients with an anterior resection of the corpus callosum show a response-based neglect, which seems to be mainly motor in nature.

One other finding of interest is that all 4 patients showed a reversal of the usual effect of line position. In control participants, the leftward bias is typically larger when the lines are located to the left or in the center than when they are located to the right (for review, see Jewell & McCourt, 2000). This line-position effect was also observed in a previous study using a line-bisection task identical to that used here (Hausmann et al., 2002). Bowers and Heilman (1980) and Kinsbourne (1970) suggested that the line-position effect might be explained in perceptual terms, such that the line located to the left leads to a greater right-hemisphere engagement and hence leads to greater attentional bias to the left. In the present study, however, there was a right bias when the lines were located to the left and a left bias when the lines were located to the right. The effect was found consistently in 4 patients, suggesting that it is independent of the callosal region that is sectioned. It is unclear why this pattern emerged, although it might reflect an overcompensation toward the objective center.

In sum, the results suggest that the corpus callosum does play a role in line bisection, but the effects of callosal section can be surprisingly complex. Normal line bisection is probably a function of the right hemisphere, which can direct attention to both sides of space, albeit with a slight left bias. The posterior callosum appears to be responsible for the transfer of spatial information that permits the right hand as well as the left hand to bisect lines on the basis of the right-hemispheric representation. Anterior callosal lesions have little effect on line bisection, except insofar as they encroach on posterior regions. The more the encroachment, the less the transfer, so that line bisection tends toward the symmetrical pattern shown in young children, with the left hand showing a left bias and the right hand a right bias. However, complete section of the splenium, or total callosotomy, can result in consistent neglect, presumably because one or the other hemisphere takes charge, regardless of the hand used. In the case of the patient with posterior callosotomy there was consistent left neglect, suggesting right-hemispheric control, whereas the patient with full callosotomy showed consistent right neglect, suggesting left-hemispheric control. It remains to be seen whether these patterns apply to other patients with comparable callosal sections, or whether these patterns are idiosyncratic to the patients we studied.

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