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Line bisection following hemispherectomy

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Abstract

Two left- and right-hemispherectomized patients with contralateral hemianopia and 20 normal controls were administered a line bisection task. All hemispherectomized patients showed a strong bisection bias towards their blind visual field. This contralateral bias persisted when patients were forced to start scanning within their blind hemifield, supporting the idea of a strategic adaptation of attention towards the blind visual field. In all patients the hemispherectomy was performed as a result of cortical abnormality (congenital or acquired) and therefore early changes in functional cerebral organization may have occurred in these patients. The absence of a neglect-like ipsilateral bias and the presence of a hemianopic-like contralateral bias in line may represent a functional deficit or suggest that plastic changes following hemispherectomy induced an adaptive functional re-organization of spatial attention in both left- and right-hemispherectomized patients.

Keywords: Functional cerebral asymmetry; Hemianopia; Lateralization; Pseudoneglect; Neglect

1. Introduction

Unilateral brain damage to the right hemisphere can result in a lack of awareness of visual stimuli in the left side of visual space. Typically this left-sided contralateral neglect results from damage to the posterior parietal lobe, although recent studies also implicate the right superior temporal cortex (Karnath, Ferber, & Himmelbach, 2001; Karnath, Himmelbach, & Rorden, 2002).

The line bisection task has often been used to assess left-hemineglect. Neglect patients normally tend to deviate to the right of the objective middle when bisecting horizontal lines. This observation is compatible with the idea that the left hemisphere is concerned almost exclusively with attention to the contralateral right hemispace, whereas the right hemisphere is capable of directing attention to both sides of space, although it does tend to favor the contralateral left side (Heilman & Valenstein, 1979; Heilman & Van Den Abell, 1980; Mesulam, 1981).

After unilateral brain damage, visual neglect often co-occurs with visual field deficits (i.e. hemianopia in the contralateral visual field); however, only a few studies have investigated the effect of hemianopia on line bisection (Barton & Black, 1998). Using a manual line bisection task with unlimited viewing time, Barton and Black (1998) found that, as expected, neglect patients err to the right of the objective middle (ipsilateral to the lesion). In contrast, patients with a right or left hemianopic visual field defect showed a bias that was contralateral to the defect. This finding was contrary to expectation because patients with a left hemianopia see only the right part of the line, which should have resulted in a bias to the right. The authors concluded that the contralateral bias in hemianopia might represent "either non-veridical spatial representation within a visual hemifield or a consequence of the strategic adaptation of attention into contralateral hemispace" (p. 660).

A bisection bias toward the blind hemifield has also been shown by Kerkhoff (1993) who investigated six patients with homonymous altitudinal scotomata, four of whom had additional hemianopic scotomas. In horizontal-bar bisection all four patients with left- or right-sided homonymous hemianopia without neglect showed a bias towards the contralateral hemifield. Similarly, in vertical-bar bisection all six patients showed a bias towards the upper or lower hemifield. The author argued that the location of the field defect predicts the direction of the bisection error (towards the scotomatous field), but not the *degree* of error.

Thus, patients with hemianopia without neglect and patients with neglect without hemianopia tend to show opposite shifts in bias during manual line bisection. Kerkhoff (1993) speculated that patients with both neglect and hemianopia should have a smaller bisection error than patients

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with either hemianopia or neglect "because the effects of both disorders would subtract from each other" (p. 264). Some studies, however, have failed to find significant differences between neglect patients with and without hemianopia (Halligan, 1999; Halligan, Marshall, & Wade, 1990) and others have found a stronger ipsilateral bisection bias in neglect patients with hemianopia compared with neglect patients without hemianopia (Doricchi & Angelelli, 1999; Doricchi, Galati, DeLuca, Nico, & D'Olimpio, 2002; Doricchi, Onida, & Guariglia, 2002).

Overall, then, manual line bisection appears to be useful in differentiating between patients with hemianopia versus patients with neglect (with or without hemianopia). It is more difficult to differentiate between neglect patients with and without hemianopia, because both groups show an ipsilateral bisection bias that only differs in degree (Kerkhoff & Schindler, 1997).

With regard to the contralateral bias observed in pure hemianopic patients, it is likely that this effect is a consequence of strategic adaptation of attention toward the contralateral hemispace. For example, hemianopic patients show a gradient of fixation with increased search in their contralateral visual field (Behrmann, Watt, Black, & Barton, 1997). During line bisection a similar attentional gradient is observed in that these patients tend to search for the end of the line in their blind hemispace (Barton, Behrmann, & Black, 1998; Ishiai, Furukawa, & Tsukagoshi, 1987, 1989). The observed bias may therefore be the result of a compensatory mechanism in individuals aware of their visual loss. As further support for this, hemianopic patients have been reported to fixate most frequently at the ends of lines in their contralateral (blind) hemispace during line bisection, whereas the distribution of fixation in normal controls was most dense at the center of the line (Barton et al., 1998).

Based on the assumption that the right hemisphere is dominant for spatial awareness, patients who have had their left or right cerebral hemisphere surgically removed offer a valuable opportunity to evaluate hemispheric contribution to spatial awareness. Moreover, due to the fact that hemispherectomized patients show a complete hemianopia in the contralateral visual field, it is possible to investigate the effect of visual field defects in line bisection.

In the current study, four hemispherectomized patients were administered a line bisection task. Two of the patients underwent resection of the left cortex (M.J. and S.F.) and two underwent resection of the right cortex (B.P. and J.F.) and all are aware of their visual loss. Of particular interest was whether the findings would be consistent with the earlier line bisection studies with hemianopic patients (i.e. contralateral bias, possibly as a result of a strategic adaptation).

Another factor of particular importance was the effect of scan direction—that is, instructing the participant to start inspecting line from the left (left-to-right scanning) or the right (right-to-left scanning) endpoint prior to the bisection. In the vast majority of visual line bisection studies using method-of-adjustment procedures, subjects are allowed virtually unlimited time to visually inspect the stimuli. Thus there is the potential for subjects to adopt strategies that involve systematic scanning of the lines. Neurologically normal subjects tend to show a bias in the direction from which scanning is initiated. That is, subjects scanning from left-to-right err significantly to the left of the veridical line midpoint, whereas subjects scanning from right-to-left make modest rightward errors. These directional effects, often reported in research with both normal subjects and neglect patients (Chokron, Bartolomeo, Perenin, Helft, & Imbert, 1998; Chokron & De Agostini, 1995; Jewell & McCourt, 2000), have not been previously investigated in hemispherectomy patients.

2. Methods

2.1. Subjects

2.1.1. Left hemispherectomy

M.J. is a 41-year-old woman who was admitted to surgery at the age of 8 years because of intractable epilepsy. She was diagnosed with hemiplegia at 8 months and, throughout childhood, her seizures continued despite frequent changes of anticonvulsant medication. Psychological assessments during this period revealed progressive mental and behavioral deterioration. Air encephalography revealed gross atrophy of the left cerebral hemisphere with midline displacement. It was considered that occlusion of the middle cerebral artery was the original source of the damage.

The entire left cerebral cortex was removed during the procedure, including the temporal structures and hippocampus. At 2 months follow up, her physical condition was good and her behavior had improved significantly. The intellectual decline was halted and almost 2 years after the operation her verbal IQ was 79, performance IQ 65, and full scale IQ 70. When she was 30 years old, M.J. had further assessment for possible return of petit mal seizures. EEG recordings showed frequently epileptiform activity in the left central region as well as a disturbance of background activity in the same region. M.J. was put on anticonvulsive medication with good results. Both absences and tonic spasms disappeared, and there was an improvement in memory and thinking. Visual field analysis conducted using the Humphrey Visual Field Analyzer revealed a complete right homonymous hemianopia. Fixation was found to be normal, although maintenance of fixation was poor.

S.F. is a 34-year-old man who was born with Sturge–Weber Syndrome. At about 6 months it was noticed that he did not use his right arm and leg as much as the left, and at 6.5 months he had his first seizure. These continued with variable frequency of none to seven seizures per day. Additionally he showed a progressive right hemiparesis. At the age of 8 months he had a severe right hemiplegia. Movements of the right leg were normal but still more limited than those of the left leg, and reflexes were abnormally brisk.

At the age of 10 months, a hemispherectomy was recommended and carried out. The cortex of the left hemisphere was found to have some degree of atrophy. The whole left cortex was removed leaving the thalamus and basal ganglia intact. Postoperative recovery was good. S.F.'s seizures ceased entirely until the age of 5 years when he had some petit mal attacks, and was put on anticonvulsive medication. When he was 17 his full scale IQ was 64–75, his verbal IQ was 74–82, and his performance IQ was 60–70. Currently S.F. has been seizure-free for over 15 years and EEG recording in 1995 showed normal right-sided background activity during walking and attenuation of all left-sided frequencies. The Humphrey Visual Field Analyzer revealed a complete right homonymous hemianopia. Fixation was found to be central binocularly, but maintenance of fixation was poor.

2.1.2. Right hemispherectomy

B.P. is a 45-year-old man who was born with Sturge–Weber Syndrome. Left hemiplegia was apparent directly after birth, and from the age of 2 months he began having mild convulsions, which were medically well controlled. Grand mal seizures began when he was 5 or 6 years old and were not controlled by medication. An air encephalogram was performed when he was 7 years and revealed atrophy of the right hemisphere.

A hemispherectomy was performed when he was 9 years old. Pathology revealed atrophy of the cortex and angiomatosis of the surface of the brain. Following the operation he was seizure-free for 5 years and since then he had some petit mal attacks which are well controlled by medication. He still has occasional mild seizures that are triggered by stress. He has no use of his left hand. He has no vision in his right eye because the retina is affected by the increased vascularisation of the Sturge–Weber Syndrome. A Humphrey Visual Field Analysis on the left eye revealed a monocular superior visual field defect, which was more marked temporally. Although B.P. did not show a complete hemianopia, his blind field included the upper and lower left quadrant from about 20 to 30° visual angle and mainly the upper quadrant from about 0 to 20° visual angle. B.P.'s fixation was found to be central, but maintenance of fixation was poor.

J.F. is a 60-year-old woman whose birth and development were normal until the age of 5 years when an accident caused right middle-lobe pneumonia. At the age of 7 years she had several focal seizures. She was diagnosed as having a right cerebral abscess (later cleared by penicillin) that was thought to have resulted from right middle-lobe syndrome. When S.F. was 11 years old, she was admitted to hospital with gross left hemiplegia and focal epilepsy. She was noted to have a left lower motor-neurone facial palsy with diminished sensation over the trigeminal region. Her visual fields showed a homonymous defect in the left lower quadrant. At the age of 22 she had a series of grand mal seizures and also had a depressive illness requiring psychiatric treatment. Skull X-ray showed atrophy of the right hemisphere and air encephalography showed marked enlargement of the right lateral ventricle, with evidence of atrophy over the cerebral cortex especially on the right side. EEG showed a severe abnormality in the right hemisphere with epileptoform activity arising in the mid-temporal region and independently in the frontal and basi-frontal regions. Her verbal IQ was 96, performance IQ 82, full scale IQ 90.

Hemispherectomy was carried out at the age of 32. Since the operation J.F. has had no further major seizures. She continues to have petit mal seizures, particularly under stress, which are controlled by anticonvulsive medication. Visual field analysis conducted using the Humphrey Visual Field Analyzer revealed an absolute binocular left hemianopia. Fixation was found to be central bilaterally, and maintenance of fixation was good.

2.1.3. Neurologically normal controls

The control group consisted 20 participants from the University of Auckland, New Zealand. The mean age of the participants was 35.88 years (S.D. = 4.39; range: 27–41 years; $N = 8$) for males and 28.75 years (S.D. = 6.77; range: 20–41 years; $N = 12$) for females. The reading direction of all subjects was left-to-right. Those who had used any medication affecting the central nervous system during the last 6 months were excluded. All subjects had normal or corrected-to-normal visual acuity and were naive to the purpose of the study.

Due to hemiplegia of the hemispherectomized patients, all subjects were tested on line bisection using the preferred hand. Left-hemispherectomized patients (using the left hand) were compared with left-handed (LH) controls, and right-hemispherectomized patients were compared to right-handed (RH) controls (Fig. 1). Handedness of the controls was determined using the Edinburgh Handedness Inventory (Oldfield, 1971).

2.2. Procedure and materials

The line bisection task was identical to that used in previous studies (Hausmann, Ergun, Yazgan, & Güntürkün, 2002; Hausmann, Waldie, & Corballis, 2003). It comprised 17 horizontal black lines of 1 mm width on a white sheet of paper (21 cm × 30 cm). The lines ranged from 100 to 260 mm in their 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 and five lines near the right margin. The sheet was laid in front of the subject's midline.

Subjects were instructed to bisect all lines into two parts of equal length by marking the subjective midpoint of each line with a fine pencil. To control the effect of scan direction all subjects performed the task three times. No instructions about scan direction were made in the free-view condition. Then, participants were instructed to scan each line from left-to-right or right-to-left by placing the pencil at the end of each line, moving the pencil along the line until the subjective center of the line was reached, and then to set the

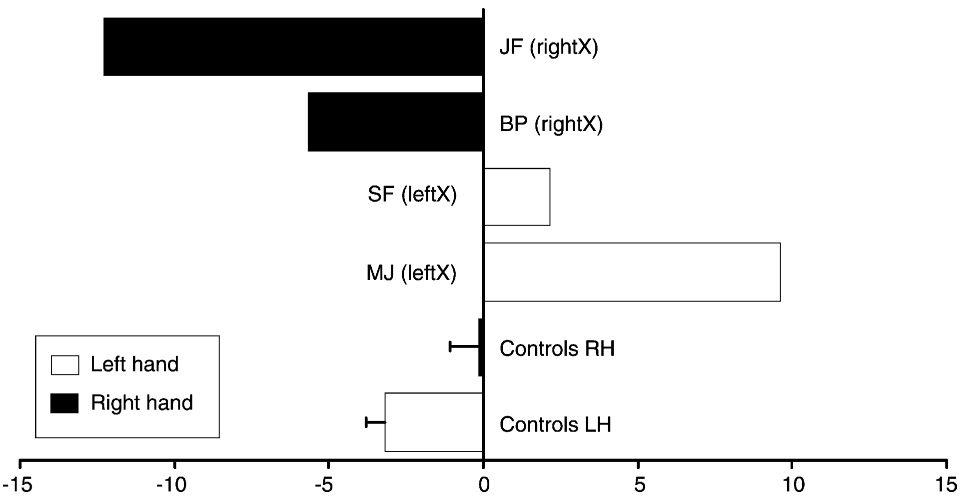

Fig. 1. Mean deviation from the true center (%) in line bisection (free-view condition) of four hemispherectomized patients with left (leftX: M.J., S.F.) and right hemispherectomy (rightX: B.P., J.F.) as well as left-handed (LH) and right-handed (RH) normal controls. Negative values indicate a bias to the left and positive values indicate a bias to the right of the objective middle.

mark. All participants started with the free-view condition first. The order of the other two scan direction conditions was counterbalanced. All subjects completed the whole task with the preferred hand under each condition. The experimenter covered each line after it was marked to ensure that the subjects 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 percent deviation score for each line was computed as: [(measured left half − true half)/true half] × 100. This procedure is comparable to that used in other studies (Scarisbrick, Tweedy, & Kuslansky, 1987; Shuren, Wertman, & Heilman, 1994). We then computed the mean score for all lines separately for each hand used. Negative values indicate a left bias, positive values a right bias.

3. Results

Presented in Table 1 are the mean percentage deviation scores (standard deviations) for left- and right-handed normal control participants as a function of line position (left, center, right) and scan direction (free-view, right-to-left, left-to-right). The descriptive statistics for the hemispherectomized patients are shown in Table 2. In order to compare the data of each hemispherectomized patient with those of the normal control group, we treated each patient as a separate group, with error terms taken from analysis of the controls.

3.1. *Control subjects*

3.1.1. *Free-view condition*

The percentage deviation scores were subjected to a line position (left, center, right) by hand preference (left, right) by sex (male, female) split-plot ANOVA. As expected, controls showed a significant leftward bias (-1.65 ± 0.57; $F(1, 16) = 8.48$, $P = 0.01$), which was especially pronounced among the left-handers when they used their preferred left hand (-3.39 ± 0.80). In contrast, right-handers showed a slight right bias with their right hand (0.08 ± 0.80), resulting in a significant handedness effect ($F(1, 16) = 9.35$, $P = 0.008$). A significant main effect of line position ($F(2, 15) = 4.35$, $P = 0.032$) showed that the bias was less pronounced when the lines were positioned to the right (-0.76 ± 0.64) relative to both the center (-2.06 ± 0.56; $t(21) = 6.21$, $P < 0.001$) and left (-2.14 ± 79; $t(21) = 2.29$, $P < 0.05$) of the page.

Table 1
Directional deviations from veridical middle (%) and standard error means for visual line bisection as a function of scan direction and line position in normal left- and right-handed controls

Line position	Left-handed controls ($N = 10$)			Right-handed controls ($N = 10$)		
	Free-view	Left-to-right	Right-to-left	Free-view	Left-to-right	Right-to-left
Left	-3.74 ± 0.86	-0.29 ± 1.16	-4.21 ± 1.04	-0.39 ± 1.25	0.03 ± 0.93	-0.01 ± 1.54
Center	-3.43 ± 0.57	-0.60 ± 0.83	-4.31 ± 0.69	-0.70 ± 0.91	0.24 ± 0.80	-2.34 ± 1.04
Right	-2.37 ± 0.81	-0.60 ± 0.66	-3.52 ± 0.83	0.95 ± 0.97	0.82 ± 0.94	-1.77 ± 1.02
All	-3.21 ± 0.57	-4.05 ± 0.73	-0.51 ± 0.76	-0.12 ± 0.94	0.34 ± 0.55	-1.61 ± 1.02

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

Table 2
Directional deviations from veridical middle (%) for visual line bisection as a function of scan direction and line position in patients with left hemispherectomy (M.J., S.F.) and right hemispherectomy (B.P., J.F.)

Line position	M.J. (left hemispherectomy)			S.F. (left hemispherectomy)			B.P. (right hemispherectomy)			J.F. (right hemispherectomy)		
	Free-view	Left-to-right	Right-to-left	Free-view	Left-to-right	Right-to-left	Free-view	Left-to-right	Right-to-left	Free-view	Left-to-right	Right-to-left
Left	15.31	2.08	22.05	1.88	−5.31	−6.84	8.52	−8.55	8.27	−8.83	−14.71	1.20
Center	7.81	−20.30	10.47	5.31	−10.52	−15.71	−3.81	−5.91	−3.16	−10.10	−9.65	−6.41
Right	6.36	−7.82	7.40	−2.01	−8.99	−16.51	−22.43	−7.64	−0.10	−18.73	−20.20	−20.21
All	9.59	−2.53	12.97	2.15	−13.34	−8.54	−5.66	−7.19	1.10	−12.66	−14.24	−8.23

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

3.1.2. Scan direction

As in the free-view condition, controls showed a leftward bias (-1.29 ± 0.47; $F(1, 16) = 7.03$, $P = 0.017$), which was slightly more pronounced among left-handers using their preferred left hands (-2.21 ± 0.67) than among right-handers using their right hands (-0.30 ± 0.67). The handedness effect approached significance ($F(1, 16) = 4.06$, $P = 0.061$). The main effect of scan direction was highly significant ($F(1, 16) = 19.94$, $P < 0.001$), indicating a strong left bias when the lines were scanned from right-to-left (-2.58 ± 0.63) and a small right bias when the lines were scanned from left-to-right (0.06 ± 0.47). No other effects were significant.

3.2. Hemispherectomized patients

3.2.1. B.P. (right hemispherectomy)

3.2.1.1. Free-view condition. Although B.P. showed a strong overall left bias (-5.91 ± 3.03), this differed only marginally from that of normal right-handed controls (-0.05 ± 0.96; $F(1, 9) = 3.40$, $P = 0.098$). However, his bias depended significantly on line position ($F(2, 8) = 145.02$, $P < 0.001$). His left bias was especially pronounced when the lines were positioned on the right side of the page (-22.43 ± 3.07), was reduced for the center lines (-3.81 ± 2.86) and shifted to a right bias when the lines were positioned on the left ($+8.52 \pm 3.97$). In contrast, the right-handed controls showed a right bias when lines were located on the right ($+0.95 \pm 0.97$) and a left bias when the lines were located in the center (-0.70 ± 0.91) or to the left (-0.39 ± 1.26).

3.2.1.2. Scan direction. Overall, B.P.'s left bias (2.85 ± 2.25) did not differ significantly from that of the controls (-0.50 ± 0.71), $F(1, 9) = 0.99$, n.s. However, his performance depended significantly on scanning direction ($F(1, 9) = 17.64$, $P = 0.002$). He showed a right bias when scanning the lines from right-to-left (1.67 ± 3.22) and a left bias when lines were scanned from left-to-right (-7.37 ± 1.66), an effect that was the opposite of that shown by right-handed controls (right-to-left: -1.37 ± 1.02; left-to-right: 0.36 ± 0.53).

3.2.2. J.F. (right hemispherectomy)

3.2.2.1. Free-view condition. J.F.'s overall left bias (-12.55 ± 3.03) differed significantly from that of right-handed normal controls (-0.05 ± 0.96; $F(1, 9) = 15.49$, $P = 0.003$). As for B.P., the left bias was especially pronounced when the lines were located on the right (-18.73 ± 3.07), but a left bias was also found when the lines were located in the center (-10.10 ± 2.86) or to the left of the page (-8.83 ± 3.97). This pattern differed significantly from that shown by the controls ($F(2, 8) = 12.08$, $P = 0.004$).

3.2.2.2. Scan direction. As in the free-view condition, J.F.'s overall left bias (-11.66 ± 2.25) differed significantly from that of the normal right-handed controls (-0.50 ± 0.71; $F(1, 9) = 22.38$, $P = 0.001$). Similar to B.P., she showed a left bias that was especially pronounced when she scanned from left-to-right (-14.85 ± 1.66, right-to-left: -8.47 ± 3.22). This pattern differed significantly from that shown by the controls (left-to-right: 0.35 ± 53; right-to-left: -1.37 ± 1.02; $F(1, 9) = 10.01$, $P = 0.011$).

3.2.3. M.J. (left hemispherectomy)

3.2.3.1. Free-view condition. M.J.'s overall bias differed significantly from that of normal left-handed controls ($F(1, 9) = 46.05$, $P < 0.001$). M.J. showed a strong bias to the right ($+9.83 \pm 1.83$), whereas the controls showed a bias to the left (-3.18 ± 0.58). Analysis of the group × line position interaction ($F(2, 8) = 6.06$, $P = 0.025$) revealed that the right bias was particularly pronounced when the lines were located to the left (15.31 ± 2.73), compared with center lines (7.81 ± 1.81) or lines on the right (6.36 ± 2.57). In contrast, the controls showed their strongest left bias when the lines were located to the left (-3.74 ± 0.86), which was slightly reduced in the center (-3.43 ± 0.57) or on the right (-2.37 ± 0.81).

3.2.3.2. Scan direction. M.J.'s overall right bias (2.31 ± 1.94) differed slightly from the left bias of controls (-2.25 ± 0.61) and the difference approached significance ($F(1, 9) = 5.04$, $P = 0.051$). His right bias was especially pronounced in the right-to-left condition (13.31 ± 2.34), and she showed a left bias during left-to-right scanning (−8.68 ± 2.42). The effect of scan direction differed significantly from that shown by the normal controls ($F(1, 9) = 78.47$, $P < 0.001$), who showed a left bias in both scan-conditions (right-to-left: −4.01 ± 0.74; left-to-right: −0.50 ± 0.76).

The group by line position interaction ($F(2, 8) = 67.17$, $P < 0.001$) and the group by scan direction by line position interaction ($F(2, 8) = 12.68$, $P = 0.003$) were significant. M.J. showed a consistent right bias when the lines were scanned from right-to-left. This right bias was especially pronounced when the lines were located on the left. When M.J. scanned the lines from left-to-right, she showed a small right bias only when the lines were located to the left. In contrast, controls showed a consistent left bias over the line positions under each scan condition, which was larger when the lines were scanned from right-to-left.

3.2.4. S.F. (left hemispherectomy)

3.2.4.1. Free-view condition. S.F. showed right bias (1.73 ± 1.83), which was significantly different from the left bias of normal left-handed controls (−3.18 ± 0.58; $F(1, 9) = 46.05$, $P < 0.001$). A significant group by line position interaction ($F(2, 8) = 6.06$, $P = 0.025$) revealed that, in contrast to controls, S.F. showed a right bias when lines were located on the left (1.88 ± 2.73) or in the center (5.31 ± 1.81), but a left bias when the lines were located on the right (−2.01 ± 2.57).

3.2.4.2. Scan direction. In contrast to the free-view condition, S.F. showed a overall left bias (−10.65 ± 1.94) which differed significantly from the left bias of controls (−2.25 ± 0.61; $F(1, 9) = 17.02$, $P = 0.003$), but did not differ significantly with scan direction. S.F. showed a strong left bias in right-to-left (−13.02 ± 2.34) and left-to-right scanning (−8.27 ± 2.42). Controls also showed a strong left bias in both scan-conditions (right-to-left: −4.01 ± 0.74; left-to-right: −0.50 ± 0.76). The interaction between group and line position was significant ($F(2, 8) = 8.26$, $P = 0.011$). S.F. showed a large left bias when lines were located on the right (−12.75±1.42) or in the center (−13.12±2.15), which was reduced when the lines were on the left (−6.08 ± 2.90). In contrast, controls showed a left bias that was relatively robust over the line positions (left: −2.25 ± 0.92; center: −2.46 ± 0.68; right: −2.06 ± 0.45).

4. Discussion

All hemispherectomized patients in the present study showed a line bisection bias contralateral to their removed hemisphere in the free-view condition. Both patients with a right hemispherectomy showed a strong left bias, whereas both left-hemispherectomized patients erred to the right of the objective middle. Thus, the bisection bias was consistently within the blind (hemianopic) visual field, regardless of which hemisphere was removed.

The main finding is consistent with earlier studies with hemianopic patients (Barton & Black, 1998; Doricchi & Angelelli, 1999; Doricchi et al., 2002; Gassel & Williams, 1963a,b; Kerkhoff, 1993). Individuals with hemianopia but without neglect typically show a bisection bias contralateral to their lesion. In contrast, neglect patients show an *ipsilateral* bisection bias that is especially pronounced with concurrent hemianopia (Barton & Black, 1998; Doricchi et al., 2002; Zihl & von Cramon, 1986). This suggests that hemianopia exacerbates hemineglect (Doricchi & Angelelli, 1999; Doricchi & Galati et al., 2002) rather than abolishing neglect (Kerkhoff, 1993; Ogden, 1985). Together the results indicate that the contralateral line bisection bias is a function of complete hemianopia rather than hemineglect.

Most patients with homonymous hemianopia appear to compensate for their visual field defects. As noted by Gassel and Williams (1963a,b) and later by Barton and Black (1998), many factors may contribute to these (conscious and/or unconscious) strategies. With regard to the contralateral bias observed during line bisection, it has been suggested that patients strategically allocate attention towards the blind hemifield (Barton & Black, 1998). This possibility is supported by the study of Behrmann et al. (1997), who showed that hemianopic patients display an eye-fixation gradient weighted towards contralateral space. Ishiai et al. (1987) similarly found that hemianopic patients concentrate fixation in the periphery of their hemianopic field during line bisection, and later noted (Ishiai et al., 1989) that they often scan the ends of the lines. The hemispherectomized patients in the current study may have adapted to their visual loss by allocating attention to their blind visual field.

Uncontrollable eye movements towards the hemianopic side may also account for the contralateral bias effect. As reported by Gassel and Williams (Gassel & Williams, 1963a), hemianopic patients are frequently unaware of abrupt eye movements to their blind hemifield during search tasks. In an electro-oculography study by Gassel and Williams (Gassel & Williams, 1963a,b), the majority of patients showed deviation of the eyes to the hemianopic side (only two of 25 normal subjects showed a lateralized deviation), suggesting a tonic oculomotor imbalance. Three patients with hemispherectomy also showed an eccentric deviation towards the hemianopic side (two showed disturbed fixation). This deviation was greatest when a target was on the same side as the lesion (Gassel & Williams, 1963a). In the present study, oculomotor weakness and disturbed fixation may have impacted upon line bisection performance. Three of the four participants had been previously found, during routine optomological testing, to have difficulties maintaining fixation.

Also consistent with the above study, we found an enhanced contralateral line bisection bias in all hemispherectomized patients when the lines were located within their ipsilesional hemispace. Both right-hemispherectomized patients showed an overall left bias, which was especially pronounced when lines were located to the right, whereas both left-hemispherectomized patients showed an overall right bias, which was especially pronounced when lines were located to the left. It is possible that patients with complete hemianopia try to estimate the extent of the line in the contralateral hemispace by using the information within their ipsilateral hemifield. If the extent of the line in the ipsilateral hemifield is large, they might overestimate the length of the line within their contralateral blind hemifield, perhaps by using the size of the sheet of paper as spatial framework. In the control subjects, the typical left bias was less pronounced when the lines were located to the right, which is consistent with earlier results ((Luh, 1995); see review (Jewell & McCourt, 2000)).

Kerkhoff and Schindler (Kerkhoff & Schindler, 1997) argued that the contralateral line bisection bias does not change if the hemispherectomized subjects are forced to look at the hemianopic side. Similarly, the results of the current study show that the bisection bias in hemispherectomized patients was very similar to the free-view condition when they start scanning the line within their blind hemifield. This might indicate that the patients also started scanning the lines within the blind hemifield in the free-view condition.

The left bias for the right-hemispherectomized patients in both conditions (free-view and left-to-right scan) was not only in the same direction, but also of similar size. The contralateral bias was even larger when patients were instructed to start scanning within their blind hemifield. A similar pattern but in the opposite direction was found for one left hemispherectomy patient (S.F.) but not for the other. In general, however, the findings support the idea that hemianopic patients use scan strategies to perform the task. Scan strategies might also explain the difference in performance observed between hemianopic versus neglect patients. That is, hemianopic patients tend to have insight into their visual problems in daily life and are thus aware of their hemianopia (Kerkhoff & Schindler, 1997), whereas neglect patients typically do not.

As mentioned by Kerkhoff (1993), however, the location of the field defect seems to predict the direction of the bisection error (i.e. towards the scotomatous field), but not the degree. In support, the contralateral bisection bias reported here differed in degree across the four hemispherectomy patients. As argued by Gassel and Williams (Gassel & Williams, 1963a,b), this variability might therefore be partly due to heterogeneity in tonic ocular imbalance. Despite the heterogeneity, however, most patients appear to compensate by making appropriate eye and head movements, which include directing longer fixations towards the hemispace contralateral to injury (Meienberg, Harrer, & Wehren, in press).

It is possible that compensatory eye movements in patients with hemispherectomy might be influenced by extrageniculate striate pathways (Meienberg et al., in press). Electrophysiological and anatomical evidence suggests that the retino-collicular pathway does not degenerate completely as a result of cortical hemispherectomy, and is capable of processing visual inputs (Azzopardi, King, & Cowey, 2001). Given that it is possible to elicit implicit behavioral responses to visual stimuli in the blind field (King, Azzopardi, Cowey, Oxbury, & Oxbury, 1996; King, Frey, Villemeure, Ptitio, & Azzopardi, 1996), voluntary responses to visual stimuli presented in the blind field may be mediated by intact extrastriate cortex (Azzopardi et al., 2001).

Ptito, Fortin & Ptito (2001) confirmed that residual vision, with awareness, can occur in the blind field of hemispherectomy patients. Two hemispherectomized subjects were tested with an eye-tracker that allowed the stimulus display to be stabilized retinally, and thus exclude the potential effects of eccentric fixation or eye movements. Stabilized field mapping identified an area in both subjects' hemianopic field within which stimulus detection was possible. However, Ptito et al. (Ptito, Lepore, Ptito, & Lassonde, 1991) later suggested that subcortical structures such as the superior colliculi and/or the pulvinar thalami (possibly in conjunction with the remaining hemisphere) might be responsible for the residual visual abilities of hemispherectomy patients.

There is therefore a strong possibility that the remaining hemisphere of hemispherectomy patients plays a role in the mediation of residual visual abilities in the blind field. This would be achieved by a process of cortical plasticity and/or by utilization of existing neural pathways such as subcortical nuclei (Ptito et al., 2001).

With regard to the neurologically normal individuals in the present study, these subjects showed the "normal" left bias in line bisection. Also consistent with earlier research was the finding that this effect was particularly pronounced in left-handed subjects when using their preferred left hand. The difference between left- and right-handed controls is most likely a function of hand use, not of handedness per se. A stronger left bias with the left hand than with the right hand in right-handers is well known (Brodie & Pettigrew, 1996; Hausmann et al., 2002, 2003; Mesulam, 1981; Shuren et al., 1994).

In sum, all hemispherectomized patients in this study showed a strong contralateral bias (an absence of a neglect-like ipsilateral bias), suggesting that line bisection performance is strongly influenced by hemianopia. Although we can not rule out the possibility that the strong contralateral bias represents a deficit due to massive structural changes, similar findings with hemianopic patients without neglect have been explained by the presence of compensatory strategies and may depend on the head and body centered representations of the contralesional space (Doricchi et al., 2002). Doricchi et al. argued that these representations might contribute to awareness of the hemianopia, and favor the "development of a representational overcompensation of sectors of horizontal space falling in the blind hemifield" ((Doricchi et al., 2002), p. 1126). In left- and right-hemispherectomized patients, plastic changes following hemispherectomy may therefore have resulted in an adaptive re-organization of spatial attention.

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