1984 (232)

Brain (1984), **107**, 95 106

LEFT HEMISPHERE INVOLVEMENT IN LEFT SPATIAL NEGLECT FROM RIGHT-SIDED LESIONS

A COMMISSUROTOMY STUDY

by GILLES PLOURDE[1] *and* R. W. SPERRY

(*From the Division of Biology, California Institute of Technology, Pasadena, California 91125, USA*)

SUMMARY

Current views of the unilateral neglect syndrome caused by right-sided focal lesions generally imply that the left hemisphere is lacking in awareness for the left half of the body and surrounding space. Questioning this assumption on the basis of previous split-brain and hemispherectomy observations, we applied lateralized tests for left hemineglect in three subjects with complete forebrain commissurotomy. Results for the left disconnected hemisphere revealed substantial awareness for the left side of the body and also for extrapersonal space, far greater than suggested by the unilateral lesion data. It is inferred that the left hemisphere, functioning independently, possesses the requisite cognitive mechanisms needed to prevent the appearance of the typical neglect syndrome as observed following right-sided lesions. It is proposed that the eventual explanation of this disorder must therefore account for the lack of left hemisphere compensation.

INTRODUCTION

The predominant role of right hemisphere lesions in the aetiology of unilateral neglect or hemi-inattention is still unexplained (Friedland and Weinstein, 1977). While minor attentional deficits for the contralateral half of space may follow injury to either cerebral hemisphere, the characteristic syndrome of pronounced unilateral neglect for one half of surrounding space or of the body itself is most frequently produced by lesions of the right hemisphere in right-handed patients (Friedland and Weinstein, 1977; Heilman and Watson, 1977*a*, *b*; Hécaen and Albert, 1978). Proposed explanations generally assume that the functional loss within the damaged right hemisphere is a sufficient basis for the disorder (Lhermitte, 1939; Brain, 1941; McFie *et al.*, 1950; Denny-Brown *et al.*, 1952; Hécaen and de Ajuriaguerra, 1952; De Renzi *et al.*, 1970; Gainotti *et al.*, 1972; Heilman and Watson, 1977*a*, *b*; Geschwind, 1981). It is tacitly implied that the undamaged left hemisphere by itself has no

[1] Present address: Laboratoire Théophile Alajouanine, Centre Hospitalier Côtes-des-Neiges, 4565, Queen Mary Road, Montreal, PQ, Canada H3W 1W5

capacity for awareness of the left side. Some recent interpretations (Kinsbourne, 1970; Heilman and Watson, 1977*a*, *b*; Heilman and Valenstein, 1979; Heilman and Van Den Abell, 1980) suggest that hemi-inattention may result from a 'hypo-aroused' or 'hypo-activated' state of the damaged right hemisphere relative to the intact left hemisphere, the latter therefore assuming control of behaviour. In these models it is also assumed that the left hemisphere is intrinsically unable to attend to the left half of space and of the body.

The absence of significant hemineglect following right hemispherectomy (Smith, 1969, 1972), however, and also following forebrain commissurotomy (Sperry *et al.*, 1969; Joynt, 1977) would seem to indicate, in contradiction to the foregoing, that the left hemisphere, under these conditions at least, has the ability to attend to both sides of the body and of extrapersonal space. In line with this, it is difficult to understand how the intact cognisant left hemisphere of an alert and linguistically competent patient would fail to notice blunders such as repeatedly raising the right arm instead of the left, grooming only the right half of the body or ignoring the contents of the left half of a dinner plate (Hécaen and de Ajuriaguerra, 1952; Oxbury *et al.*, 1974; Gardner, 1976; Heilman and Watson, 1977*b*). Equally difficult to reconcile with the known capacities of an intact left hemisphere is the tendency to represent in drawing only the right half of an object and the peculiar reluctance to correct omissions when they are pointed out, as well as the frequent association with certain other behavioural disorders (Weinstein and Friedland, 1977).

It would thus appear that more is involved than a mere loss of right hemisphere functions, and that the processing in the intact left hemisphere is also affected at a cognitive level. The symptoms and evidence relating to lateral neglect are in conformance, overall, with the possibility that (1) the left hemisphere possesses adequate mechanisms for attending to, and acting in, both halves of space, but that (2) those mechanisms mediating left-sided awareness are subject to differential suppression in the presence of the cerebral commissures *via* disruptive influences from a focally damaged right hemisphere. To explore this hypothesis further in the present study we tested the left hemisphere for left-sided awareness in commissurotomy subjects in whom there are more reliable means for determining directly, through lateralized testing, what capacities are present in each hemisphere.

As a general rule, commissurotomy subjects have shown little or no hemineglect under conditions of unrestricted, nonlateralized testing (Sperry *et al.*, 1969). With lateralized tests examples of hemineglect are, of course, evident among disconnection phenomena. These differ, however, from the classical neglect syndrome in that they are readily accounted for by commissure section, occur in either hemifield without preference, and do not seem to involve the kinds of cognitive loss described above. In the present tests we have focused on the assessment of the left hemisphere capacity for localization of left bodily parts and for performing a line bisection test.

METHODS

Subjects

The study was conducted with three subjects (L.B., N.G., R.Y.) who had undergone presumed complete surgical section of the corpus callosum along with the anterior and hippocampal commissures. The surgery had been carried out fifteen, seventeen and fourteen years earlier, respectively, for relief of intractable epilepsy. L.B. and N.G. are thought to have the least amount of extracallosal brain damage even though no localized lesion could be found in R.Y. The individual case histories are presented in further detail elsewhere (Bogen *et al.*, 1965; Bogen and Vogel, 1975).

Left Hemibody Neglect

The test procedures were based on the tendency of hemiasomatognostic patients to make errors such as raising the right arm when requested to raise the left or both arms, or touching the right ear when requested to touch the left or both ears (Hécaen and de Ajuriaguerra, 1952; Critchley, 1953; Fredericks, 1969; Friedland and Weinstein, 1977; Heilman and Watson, 1977*b*; Hécaen and Albert, 1978). In the present study similar requests were made to commissurotomy subjects in a manner such that only the left hemisphere received the instructional information indicating which command to perform. The instructional inputs were presented first in the tactile modality and, later in separate tests, in the visual modality.

Testing procedures for tactile input. On each trial one of the three plastic capital letters R, L, or C, 5 cm high, was placed in reach of the left or right hand of the subject for tactile identification out of sight behind a screen. The subject was instructed orally that he was to execute a certain command that would involve, on a given trial, performance either on the right side, the left side, or the centre of his body, depending on whether the plastic cut-out letter R, L or C, respectively, was presented. Blind palpation of the letter with one hand ensured that only the contralateral hemisphere received sufficient information to determine the task instruction. The subject was instructed not to speak during the testing and the wrist of the subject was held firmly against the table to eliminate cues from proximal arm and shoulder movement during the process of manual palpation. Trials were presented in blocks of 30 with each instruction letter appearing ten times per block in a pseudorandom order.

Individual subjects participated in four or more testing sessions conducted at least two days apart. In the first of the test series, subjects were instructed to respond by pointing to the right ear, left ear or chin when the letter R, L or C was presented. The hand used for pointing was the same as that used for identification of the instructional letter. The right hand was used first for a block of 30 trials, followed by the left hand on a different randomized sequence of 30 trials. The same procedure was repeated in another session in order to obtain 60 trials for each hand.

In the second test series, the subjects were instructed to respond by raising the right arm, the left arm, or by tapping the centre of the table in front of them when the letter presented was R, L or C, respectively. Otherwise the procedures were the same as those used in the first series, except that the instructional sequences were varied. The test tasks were designed to be sufficiently simple that failures could not easily be attributed to the task complexity or to inability to comprehend the general instructions.

Control trials were conducted before and after the test series described above to ascertain that the information necessary for tactile identification of the latter remained available only to one hemisphere, that is, to the hemisphere contralateral to the hand used for palpation. In the control trials the subject was required to identify by palpation a letter, presented as above, and then to retrieve the letter among the three possible choices by using either the ipsilateral or contralateral hand. At least 45 trials were presented to each hand for each retrieval condition.

Testing procedures for visual input. The subject, seated at a table in front of the tachistoscope (Gerbrands Model No. T2BC coupled with a timer), was told to hold his gaze on a central fixation point on the screen. Three words were then flashed in quick succession comprising a simple command to be obeyed, such as 'Raise your hands', or 'Touch both ears'. Each word was exposed for 150 ms to the right of the fixation point. Table 2 shows the commands which were used, in the order of presentation. It has been generally established that commissurotomy subjects are not able to obey verbal commands presented in this manner to the left visual field. This was used to evaluate the adequacy of the input lateralization by running control trials at the end of the session with the same words presented in the same way to the left visual field.

Stimulus cards consisted of rectangular pieces of white cardboard on which the word to be presented was printed in black capital letters. Each word, presented horizontally, subtended a visual angle of 2.5 to 5 deg depending on the number of letters. The medial edge of each word was placed 1 deg off the field centre. Three exposures, a few seconds apart, were required for each command. The subject's dominant (right) eye, with visual acuity at least equal or corrected to 20/25, was used for stimulus viewing, the other being covered with a patch. Just before the presentation of each word, the examiner said 'ready' to warn the subject to maintain fixation carefully. Two practice instructions ('touch your nose'; 'close your eyes') were given to acquaint subjects with the procedure. Nothing was said beforehand about the instructions except that they consisted of three words and the subjects were asked to refrain from speaking during the testing. The same procedure was repeated with left visual field presentations.

Hemispatial Neglect

Both disconnected hemispheres were tested independently for evidence of contralateral neglect. The line bisection test (Critchley, 1953) as modified for blind tactile performance (Bowers and Heilman, 1980) was used to obtain lateralization to left and right hemispheres. The test was presented to both hands for synchronous performance in order to occupy each hemisphere fully and prevent crossing of information or output. Two wooden rods of unequal length, varying from 12 to 24 cm, were presented out of sight one to each hand and the subject's task was to estimate the midpoint of each stimulus with the corresponding hand. The subject was instructed to run the index finger of each hand along the corresponding stimulus as many times as desired, but to move both hands in synchrony and to indicate with the left and right index fingers simultaneously the estimated midpoint of both stimuli. When the subject occasionally failed to use both hands in synchrony, the trial was not scored and had to be repeated correctly. With strict adherence to this requirement, it could be assumed that the results obtained with each hand reflected processing by the contralateral hemisphere.

Stimuli and procedures. The rods were made of half-round moulding (1.5 cm wide) cut to five different lengths (12, 15, 18, 21 and 24 cm). This allowed 20 pair permutations combining stimuli of unequal length. Both stimuli were fixed in line on the longitudinal axis of a rectangular piece of cardboard (71 × 8 cm) with the other end of each stimulus placed 10 cm from the corresponding end of the cardboard. The 20 stimulus pairs were presented to the subject in a pseudorandom sequence which was used for all testing sessions. The subject was never allowed to look at the stimuli. The subject sat blindfolded at a table and performed all trials with hands uncrossed. Stimulus cards were presented horizontally flat on the table. At the start of each trial, the subject's index finger was placed at the outer end of the corresponding rod. The task was performed under four different conditions depending upon the position of the stimuli in relation to the midline of the subject's body. In condition 1, both stimuli were placed to the right of the subject who executed the task with both hands in the right hemispace. In condition 2, both stimuli were placed to the left of the subject who executed the task with both hands in the left hemispace. In condition 3, the stimulus for the right hand was placed at centre directly in front of the subject and the stimulus for the left hand was placed to the left of the subject. In condition 4, the stimulus for the left hand was placed at the centre and the stimulus for the right hand was placed to the right of the subject. Each subject completed two blocks of 20 stimuli in each condition. One practice trial preceded each block. Four testing sessions were required for each subject and the order of stimulus location was counterbalanced across sessions. The distance between the estimated and actual midpoints was measured to the nearest centimetre for each hand and was expressed as a percentage of the length of the corresponding rod. The percentage was given as + or − score depending on whether the deviation was toward the subject's right or left side, respectively.

TABLE 1. RESULTS OF TACTILE INPUT TESTS†

Instruction		*Pointing to R. ear, L. ear, or chin*		*Raising R. arm, L. arm or tapping table*	
Hand used for letter palpation		*Right*	*Left*	*Right*	*Left*
Total number correct (maximum 60)	N.G.	58*	16 n.s.	59*	26 n.s.
	R.Y.	53*	21 n.s.	56*	20 n.s.
No. correct with 'R' (maximum 20)	N.G.	20	4	20	9
	R.Y.	19	8	19	4
No. correct with 'L' (maximum 20)	N.G.	20	5	19	7
	R.Y.	20	12	19	14
No. correct with 'C' (maximum 20)	N.G.	18	7	20	10
	R.Y.	14	1	18	2

Symbols: * $P < 10^{-4}$; n.s. nonsignificant, $P > 0.1$; † L.B. excluded from analysis (*see text*)

RESULTS

Neglect of Left Hemibody

Tactile input. The results are summarized in Table 1. When using the right hand (left hemisphere input) for palpation of the letters, the subjects gave appropriate responses in a high proportion of the trials performing at a level far beyond chance prediction ($P < 10^{-4}$) (Tables of the Cumulative Binomial Probability Distribution, 1955). Inspection of the numbers of correct trials for each letter reveals that the subjects responded as well following palpation of the letter 'L' as following palpation of the letter 'R' and thus on these tests did not exhibit any tendency to ignore the left side of the body.

In sharp contrast, the subjects' performance failed to rise above chance level when they used the left hand (right hemisphere input). R.Y. tended to respond more often on the left side than on the right, and therefore gave many (12 and 14) correct responses on trials with the letter 'L'. His overall performance, however, remained at chance level. It is not possible here to determine whether the subjects' failure with the right hemisphere resulted from inability to associate the appropriate instruction with a given letter or from other possible causes. However, this is not of direct concern since the aim of the tests was to evaluate left hemisphere capacity in isolation.

In control trials ipsilateral retrieval was performed correctly at levels of 85 per cent or higher whereas with contralateral retrieval, the percentage of correct responses fell to less than 45 per cent for N.G. and R.Y. (chance level is 33 per cent), but remained about 90 per cent for L.B. These figures confirm that the instructional input was adequately lateralized in N.G. and R.Y. In L.B., however, who is noted for exceptional development of cross-integrative strategies, the control tests indicated that the instructions were not being adequately lateralized and therefore L.B. has been excluded from the analysis.

Visual input. Table 2 shows the results obtained with right visual field presentations. Following commands that called for only one bodily part to be moved or pointed to, the subjects gave correct responses in all but one instance and showed no evidence of neglect of the left hemibody, in conformance with the results obtained with tactile input.

When the command specified two (homotopic) bodily parts, N.G. and R.Y. showed evidence of some left hemibody neglect, ranging from slight delay in the onset of response to complete absence of response. Most omissions occurred following the rather ambiguous commands employing the word 'your' instead of

TABLE 2. RESPONSES FOLLOWING RIGHT VISUAL PRESENTATIONS

Commands	*Responses* *R.Y.*	*N.G.*	*L.B.*
Raise your hands	Omission left	C	C
Touch your ears	Omission left	C	C
Touch your knees	Omission left	Omission left	C
Show your thumbs	Omission left	Delay left	C
Show your elbows	Omission left	C	C
Raise both hands	Omission left	C	C
Touch both ears	C	C	C
Touch both knees	Delay left	Delay left	C
Show both thumbs	Omission left	C	C
Show both elbows	C	C	C
Touch left ear	C	Opposite	C
Touch right ear	C	C	C
Show right thumb	C	C	C
Raise right hand	C	C	C
Raise left hand	C	C	C
Touch left elbow	C	C	C
Touch left knee	C	C	C
Show left thumb	C	C	C
Touch right knee	C	C	C
Touch right elbow	C	C	C

C = correct response. Delay = trials requiring response on both sides and in which response on side indicated after 'Delay' was slower and less affirmative than on the other side. Omission = trial requiring response on both sides and in which the subject failed to respond on side indicated after 'Omission'. Opposite = trial in which subject responded on side opposite to that specified by instruction. These four categories of responses are mutually exclusive.

'both', indicating that the mild neglect observed tended to disappear following more explicit instructions. These minor manifestations of neglect are more characteristic of the parietal akinesia observed following damage to either parietal lobe (Critchley, 1953) than of the kind of neglect typical of right hemisphere lesion.

In control trials presented to the left visual field, N.G. and R.Y. characteristically failed to respond and vocally denied having seen any word. L.B., on the other hand, reported having seen something but was unable to carry out the commands. These findings confirm that the instructional input was adequately lateralized in all three subjects.

Hemispatial Neglect

Results of the rod bisection test for awareness in extrapersonal space are presented in fig. 1, A and B, for the right and left hand, respectively. Subjects made substantial errors in estimating the midpoint of the rods. The magnitude of errors was comparable for both hands when subjects were pooled. The direction of errors appeared, however, to be influenced differently for each hand. For the left hand, the direction of errors changed with the subjects rather than with the location of stimuli; thus N.G. always erred to the left, R.Y. always to the right. In contrast, all three subjects tended with the right hand to err towards the body midline (i.e. to the left in right hemispace and to the right in the left hemispace) and thus seemed influenced by the location of stimuli. It is not clear how this difference between hands or hemispheres could be related to the classical phenomenon of spatial neglect.

Because of low accuracy in the execution of the task and of the absence of clear manifestations of unilateral neglect, adequate interpretation of the data required further knowledge as to how lesion patients with classical left hemineglect would

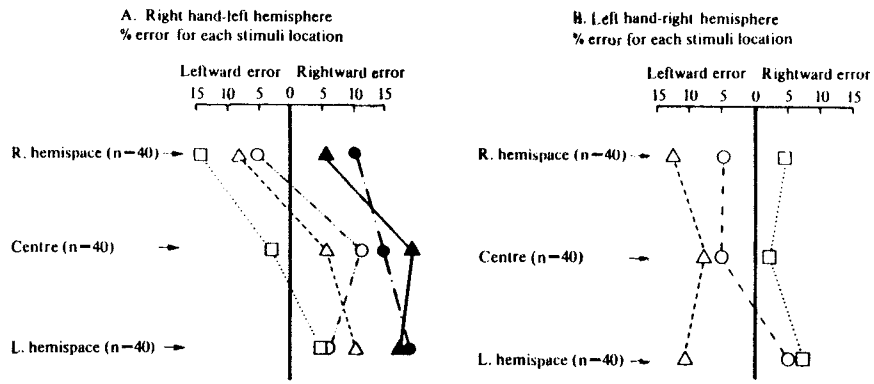

FIG. 1A and B show mean distance (% rod length) between the estimated and actual midpoints for each stimulus location (40 trials) for the right and left hand, respectively. Standard errors are roughly equal to the width of the symbols. Results of two patients (N1, N2) with left unilateral neglect caused by right hemisphere damage are also included in A for comparison. R.Y. = □; N.G. = △; L.B. = ○; N1 = ▲; N2 = ●.

perform the rod bisection test used above. We therefore administered this task to 4 right-handed patients who had sustained right hemisphere damage. The diagnoses were fronto-temporo-parietal infarction in N1 and N2, and parieto-occipital tumour and parietotemporal infarction in the two other patients. The procedures were exactly the same as above except that patients used only the right hand. Two patients (N1, N2), whose results are depicted in the fig. (A) showed a typical left unilateral neglect. In contrast to the right hand performance of commissurotomy subjects, they always erred to the right of the actual midpoint irrespective of the location of stimuli. (The 2 other patients made errors of 5 per cent or less for all stimuli locations showing no significant side preference. They were more accurate than commissurotomy subjects, presumably because they had to bisect only one rod at a time rather than two concurrently as required for commissurotomy subjects.) For all stimuli locations, there was a significant difference between the pooled right hand results of commissurotomy subjects and those of N1 and N2 (Scheffé *post hoc* comparisons, df = 4,195, $P < 0.001$) (Roscoe, 1975).

The results indicate that lesions of the right hemisphere can induce on a rod bisection task a pattern of constant errors to the right that is not observed when commissurotomy patients execute the same task under left hemisphere control. The left disconnected hemisphere data revealed no evidence of left hemineglect as seen here following right hemispheric lesions.

With the left hand-right hemisphere L.B. and R.Y. likewise revealed no evidence of right hemineglect but N.G. showed large and consistent deviation to the left which might be interpreted as a right hemineglect. This last observation is not a major concern, however, since it has not been noted with the two other patients and since the present aim was to verify whether the characteristic predominance of right hemispheric lesions in producing left-sided neglect arises from an intrinsic inability of the left hemisphere.

The data were also analysed to verify an assumption that commissurotomy subjects were executing the task with each hand-hemisphere system independently. Lack of independence between both hands would presumably show up in greater errors for trials in which the length difference between both rods was large. However, no correlation between the magnitude of errors and the length difference between rods was found, suggesting that the test was executed with each hand independently.

DISCUSSION

The present findings show that commissurotomized subjects given instructional input restricted to the left disconnected hemisphere execute correctly commands involving the left hemibody, exhibiting only negligible, if any, left hemibody neglect no greater than the mild akinesia observed to follow injury to either parietal lobe (Critchley, 1953). The subjects also failed to reveal consistent evidence of unilateral neglect for the left half of surrounding space when tested with a rod bisection task executed independently by each hemisphere. Control tests showed that the inputs had been adequately lateralized and that the results reflected the performance of the unassisted left hemisphere. L.B. and N.G. likewise revealed no evidence of contralateral neglect when choosing answers for the Raven's Matrices presented visually to either hemisphere by a special optical device (Zaidel *et al.*, 1981).

In contrast to the outcome after unilateral lesions (Heilman and Watson, 1977*a*; Hécaen and Albert, 1978), the present findings indicate that the left hemisphere possesses substantial awareness for the left half of the body as well as for the left half of objects and surrounding space. We infer that the left hemisphere functioning independently possesses the requisite intrinsic cognitive mechanisms needed to prevent the appearance of the typical neglect syndrome of right hemispheric lesions (Hécaen and de Ajuriaguerra, 1952; Critchley, 1953; Fredericks, 1969; Friedland and Weinstein, 1977; Heilman and Watson, 1977*b*; Hécaen and Albert, 1978; Schenkenberg *et al.*, 1980).

Two possible objections concerning the foregoing interpretations require comment. First, it might be conceivable that the left hemisphere capacity for left side awareness was acquired only after the commissurotomy through gradual functional readaptation. This seems highly unlikely because the subjects from the start showed only minimal or no evidence of neglect even in the early postoperative period when their behaviour appeared to be mostly under left hemisphere control (Sperry *et al.*, 1969). Secondly, the neurological status of our subjects may not be representative of the normal state because of the effects of early brain damage and longstanding intractable epilepsy. This objection cannot be directly refuted but its relevance to findings such as those of the present study has so far not been substantiated. Repeated observations have revealed that the commissurotomy subjects exhibit a pattern of functional dichotomy between the right and left hemispheres that correlates well with data from hemispherectomy.

The results are taken to support the conclusion that the syndrome of unilateral neglect cannot be explained solely in terms of right hemisphere dysfunction, and thus suggest a revision in past interpretations that have focused uniquely on right hemisphere pathology in explaining the neglect syndrome. If the left hemisphere by itself possesses adequate compensatory capacities to prevent the characteristic cognitive and conceptual symptoms of neglect, as the present findings indicate, it would seem to follow that the function of these awareness mechanisms in the left hemisphere must be disrupted also by the right-sided lesions. This does not apply however to the minor manifestations of inattention, such as unilateral akinesia or sensory extinction, observed following damage to either cerebral hemisphere (Critchley, 1953) and which appear to be ascribable to disturbances limited to the involved hemisphere.

The idea that unilateral neglect is best accounted for in terms of bilateral cerebral dysfunction was first expressed, although in a different context, by Battersby *et al.* (1956). They suggested that the disorder resulted from the combined effects of defective sensory input and general mental deterioration. This interpretation has since been criticized because patients with typical neglect occasionally show no demonstrable sensory loss and frequently do not suffer from a degree of general mental deterioration sufficient to account for the marked cognitive disturbances (Hécaen, 1962; Oxbury *et al.*, 1974; Gardner, 1976). Nevertheless the collective evidence supports the presence of a bilateral cerebral dysfunction in neglect (Friedland and Weinstein, 1977; Weinstein and Friedland, 1977). Although Heilman and colleagues described bilateral but asymmetrical arousal defects in patients with neglect, they did not consider bilateral hemispheric dysfunction of primary importance in causing the neglect phenomenon in itself (Heilman *et al.*, 1978).

It thus appears that the search towards a full understanding of the neglect syndrome must include the study of the interactions and divisions of tasks between the hemispheres in addition to that of the individual capabilities of the right and left hemispheres. Our present evidence supports an interpretation along the following lines. (1) With the cerebral commissures intact, the two hemispheres may be assumed normally to work together as an integral unit (Sperry, 1977). (2) Each hemisphere probably has a capacity for exploration and representation of both sides of space. (3) The right hemisphere appears to play a leading role for cognitive operations that involve spatial relationships (*for review, see* Hécaen and Albert, 1978) as well as for certain attentional tasks (Howes and Boller, 1975; Umiltà *et al.*, 1979). Further evidence indicates that the electroencephalographic activity (spectral frequency analysis) of the right hemisphere is modified following detection of stimuli from either visual fields, whereas that of the left hemisphere is solely influenced by right visual field stimuli, supporting the contention that the right hemisphere is involved in surveying both sides of surrounding space (Heilman and Van Den Abell, 1980). (4) Where cerebral asymmetry of function has thus evolved (to avoid conflict, interference, to utilize available neural space effectively . . .) damage to the hemisphere predominantly responsible for a particular function disrupts the functioning of the entire system and thus interferes with the expression of compensatory abilities in the intact as well as in the damaged hemisphere. For left hemineglect from right-sided lesions, the leading role of the lesioned right hemisphere may be preserved even though specific spatial and attentional functions are lost with the result that the left hemisphere is suppressed and unable to exert the intrinsic potential that is present as observed in these tests.

Why then do right hemispheric lesions not cause bilateral neglect? Although it is true that right-sided lesions are not followed by severe right-sided neglect (probably because the sensory information directly conveyed to the left hemisphere is sufficiently processed to prevent such occurrences), there are indications that right-sided lesions can produce minor attentional or exploratory deficits within the right side of space (Chédru *et al.*, 1973). That study revealed that, in the absence of visual field defects, patients with right-sided lesions had visual searching times that were increased similarly for right and left placed targets, whereas patients with left-sided lesions showed increased search times only for right-sided targets.

Further work is required as the focus of this study was not directed at that particular topic.

ACKNOWLEDGEMENTS

This work was supported by Grant 03372 from the National Institute of Mental Health of the United States Public Health Service, by the F. P. Hixon Fund of the California Institute of Technology, by the Pew Trust Memorial and by a postdoctoral fellowship from the Medical Research Council of Canada. The assistance of Dr Lucie Laplante is gratefully acknowledged. We also wish to thank Dr R. Bouchard, Hôpital de l'Enfant-Jésus, Quebec, Canada, for allowing one of us (G.P.) to study patients with right cerebral hemisphere lesions.

REFERENCES

Battersby W S, Bender M B, Pollack M, Kahn R L (1956) Unilateral 'spatial agnosia' ('inattention') in patients with cerebral lesions. *Brain*, **79**, 68-93.

Bogen J E, Fischer E D, Vogel P J (1965) Cerebral commissurotomy: a second case report. *Journal of the American Medical Association*, **194**, 1328-1329.

Bogen J E, Vogel P J (1975) Neurologic status in the long term following complete cerebral commissurotomy. In: *Les Syndromes de Disconnexion Calleuse chez l'Homme*. Edited by F. Michel and B. Schott. Lyon: Hôpital Neurologique, pp. 227-253.

Bowers D, Heilman K M (1980) Pseudo-neglect: effects of hemispace on a tactile line bisection task. *Neuropsychologia*, **18**, 491-498.

Brain W R (1941) Visual disorientation with special reference to lesions of the right cerebral hemisphere. *Brain*, **64**, 244-272.

Chédru F, Leblanc M, Lhermitte F (1973) Visual searching in normal and brain damaged subjects (contribution to the study of unilateral inattention). *Cortex*, **9**, 94-111.

Critchley M (1953) *The Parietal Lobes*. New York: Williams and Wilkins.

Denny-Brown D, Meyer J S, Horenstein S (1952) The significance of perceptual rivalry resulting from parietal lesion. *Brain*, **75**, 433-471.

De Renzi E, Faglioni P, Scotti G (1970) Hemispheric contribution to exploration of space through the visual and tactile modality. *Cortex*, **6**, 191-203.

Fredericks J A M (1969) Disorders of the body schema. In: *Handbook of Clinical Neurology*. Volume 4. Edited by P. J. Vinken and G. W. Bruyn. Amsterdam: North Holland, pp. 207-240.

Friedland R P, Weinstein E A (1977) Hemi-inattention and hemisphere specialization: introduction and historical review. In: *Advances in Neurology*. Volume 18. Edited by E. A. Weinstein and R. P. Friedland. New York: Raven Press, pp. 1-31.

Gainotti G, Messerli P, Tissot R (1972) Qualitative analysis of unilateral spatial neglect in relation to laterality of cerebral lesions. *Journal of Neurology, Neurosurgery and Psychiatry*, **35**, 545-550.

Gardner H (1976) *The Shattered Mind; The Person After Brain Damage*. New York: Vintage Books.

Geschwind N (1981) The perverseness of the right hemisphere. Commentary on 'The case for mental duality: evidence from split-brain data and other considerations' by R. Puccetti. *The Behavioral and Brain Sciences*, **4**, 106-107.

Hécaen H (1962) Clinical symptomology in right and left hemisphere lesions. In: *Interhemispheric Relations and Cerebral Dominance*. Edited by V. B. Mountcastle. Baltimore: Johns Hopkins University Press, pp. 215-243.

Hécaen H, de Ajuriaguerra J (1952) *Méconnaissances et Hallucinations Corporelles*. Paris: Masson.

Hécaen H, Albert M L (1978) *Human Neuropsychology*. New York: John Wiley.

Heilman K M, Schwartz H D, Watson R T (1978) Hypoarousal in patients with the neglect syndrome and emotional indifference. *Neurology, Minneapolis*, **28**, 229-232.

HEILMAN K M, VALENSTEIN E (1979) Mechanism underlying hemi-spatial neglect. *Annals of Neurology*, **5**, 166–170.

HEILMAN K M, VAN DEN ABELL T (1980) Right hemisphere dominance for attention: the mechanism underlying hemispheric asymmetries of inattention (neglect). *Neurology, New York*, **30**, 327–330.

HEILMAN K M, WATSON R T (1977*a*) Mechanisms underlying the unilateral neglect syndrome. In: *Advances in Neurology*. Volume 18. Edited by E. A. Weinstein and R. P. Friedland. New York: Raven Press, pp. 93–106.

HEILMAN K M, WATSON R T (1977*b*) The neglect syndrome: a unilateral defect of the orienting response. In: *Lateralization in the Nervous System*. Edited by S. Harnad, R. W. Doty, L. Goldstein, J. Jaynes and G. Krauthamer. New York: Academic Press, pp. 285–302.

HOWES D, BOLLER F (1975) Simple reaction time: evidence for focal impairment from lesions of the right hemisphere. *Brain*, **98**, 317–332.

JOYNT R J (1977) Inattention syndromes in split-brain man. In: *Advances in Neurology*. Volume 18. Edited by E. A. Weinstein and R. P. Friedland. New York: Raven Press, pp. 33–39.

KINSBOURNE M (1970) A model for the mechanism of unilateral neglect of space. *Transactions of the American Neurological Association*, **95**, 143–146.

LHERMITTE J (1939) *L'Image de Notre Corps*. Paris: Nouvelle Revue Critique.

MCFIE J, PIERCY M F, ZANGWILL O L (1950) Visual-spatial agnosia associated with lesions of the right cerebral hemisphere. *Brain*, **73**, 167–190.

OXBURY J M, CAMPBELL D C, OXBURY S M (1974) Unilateral spatial neglect and impairments of spatial analysis and visual perception. *Brain*, **97**, 551–564.

ROSCOE J T (1975) *Fundamental Research Statistics for the Behavioural Sciences*. New York: Holt, Rinehart and Winston.

SCHENKENBERG T, BRADFORD D C, AJAX E T (1980) Line bisection and unilateral visual neglect in patients with neurological impairment. *Neurology, New York*, **30**, 509–517.

SMITH A (1969) Nondominant hemispherectomy. *Neurology, Minneapolis*, **19**, 442–445.

SMITH A (1972) Dominant and nondominant hemispherectomy. In: *Drugs, Development and Cerebral Function*. Edited by W. L. Smith. Springfield, Illinois: Charles C. Thomas, pp. 37–68.

SPERRY R W (1977) Forebrain commissurotomy and conscious awareness. *The Journal of Medicine and Philosophy*, **2**, 101–126.

SPERRY R W, GAZZANIGA M S, BOGEN J E (1969) Interhemispheric relationships: the neocortical commissures; syndromes of hemisphere disconnection. In: *Handbook of Clinical Neurology*. Volume 4. Edited by P. J. Vinken and G. W. Bruyn. Amsterdam: North Holland, pp. 273–290.

TABLES OF THE CUMULATIVE BINOMIAL PROBABILITY DISTRIBUTION (1955) *The Annals of the Computation Laboratory of Harvard University*. Volume 35. Cambridge, Massachusetts: Harvard University Press.

UMILTÀ C, SALMASO D, BAGNARA S, SIMION F (1979) Evidence for a right hemisphere superiority and for a serial search strategy in a dot detection task. *Cortex*, **15**, 597–608.

WEINSTEIN E A, FRIEDLAND R P (1977) Behavioral disorders associated with hemi-inattention. In: *Advances in Neurology*. Volume 18. Edited by E. A. Weinstein and R. P. Friedland. New York: Raven Press, pp. 51–62.

ZAIDEL E, ZAIDEL D W, SPERRY R W (1981) Left and right intelligence: case studies of Raven's Progressive Matrices following brain bisection and hemidecortication. *Cortex*, **17**, 167–185.

(*Received August 11, 1981. Revised April 26, 1983*)