(162) 1971

EXPRESSIVE LANGUAGE IN THE SURGICALLY SEPARATED MINOR HEMISPHERE[1]

Jerre Levy,[2] Robert D. Nebes[3] and Roger W. Sperry

(Division of Biology, California Institute of Technology, Pasadena)

The asymmetric representation of speech and writing within the dominant, usually left, hemisphere of the human brain is clearly evident in patients in whom the hemispheres have been surgically separated by midline section of the cerebral commissures (Sperry and Gazzaniga, 1967; Gazzaniga and Sperry, 1967; Gazzaniga, Bogen and Sperry, 1967). Such patients are unable, as a rule, to describe in speech or writing any stimulus information confined exclusively to the subordinate hemisphere, as by presentation to the right nostril (Gordon and Sperry, 1969), left hand, or through the left field of vision (Gazzaniga, Bogen and Sperry, 1963; Geschwind, 1965). So consistent has been this evidence that verbal expression is restricted to the major hemisphere, that the ability to respond correctly with a verbal description has come to be used in many test situations as a criterion of whether a given bit of stimulus information has been received in one or the other hemisphere.

The possibility that the minor hemisphere may, nevertheless, possess some latent verbal expression is strongly suggested in studies of aphasia. Patients with destruction of the language centers in the left hemisphere or even with complete left hemispherectomy (Smith, 1966) may still be able to sing, swear, and utter simple familiar words and phrases, including perhaps some minimal propositional speech. In

[1] Supported by USPHS Grant 03372 and the Frank P. Hixon Fund of the California Institute of Technology. Final preparation of this paper was carried out while the first author held a National Institute of Mental Health Fellowship at the University of Colorado, fellowship No. FO2 MH46980-01.

[2] Now at the Department of Psychology, University of Colorado, Boulder, Colorado.

[3] Now at Duke University, Durham, North Carolina.

current investigations dealing with cerebral lateralization of function in commissurotomy patients, it has become important to know whether certain verbal responses to left side stimuli might possibly be mediated by the minor hemisphere, or whether this has to be ruled out in favor of other interpretations.

Accordingly a more intensive effort was made, as described in the following, to demonstrate the presence of whatever linguistic expression might be present in the disconnected minor hemisphere of the commissurotomized patient.

Material and method

Subjects

The subjects were two patients of Drs. P. J. Vogel and J. E. Bogen of Los Angeles who had undergone cerebral commissurotomy for the control of intractable epileptic seizures (Bogen, Fisher and Vogel, 1965).

L.B. was 17 years old at the time of testing and had had his surgery five years previously. At the time the operation was performed, his epilepsy was diagnosed as cryptogenic in that the etiology was unknown and no neurological evidence of brain damage was found. The surgery went smoothly with apparently little trauma to the brain, L.B. being able to talk as soon as he awoke from the anesthesia. His WAIS I.Q. four years after surgery was 106 Full Scale, 110 Verbal, 100 Performance. These scores, however, do not give the full picture of L.B.'s intellectual abilities. While he deviated less than one standard deviation (SD) from the mean of his age group on 7 of the 11 subtests, on the conceptual understanding subtests, Comprehension, Similarities, and Picture Completion, he was quite superior, being 2 SD's above the mean on Similarities; on the other hand, he was 1.67 SD's below the mean on the Digit Symbol test. This wide spread in ability is indicative of abnormal brain function. Nevertheless, among the commissurotomy patients available to us for testing, L.B. had by far the fewest symptoms indicative of actual brain damage, and he therefore offered the best possibility for demonstrating minor hemisphere language.

A second subject, A.A., underwent cerebral commissurotomy at age 14. His history included a difficult forceps delivery and mild motor seizures associated with a fever several months after birth. From age five a worsening series of convulsions resulted in several falls. There were widespread EEG abnormalities over the left hemisphere, and also a moderate sensory deficit in his right hand suggesting left hemisphere damage. Postsurgical edema in the right hemisphere left him with a mildly spastic left leg, but otherwise the minor hemisphere seems to function normally.

He was administered the WAIS in 1968 and received a Full Scale score of 78, Verbal 77, Performance 82. He was less than one SD from the mean of his age group on the Picture Completion, Block Design, and Object Assembly subtests on the Performance Scale, but was one SD or more below the mean on all 6 Verbal subtests. His scores are indicative of a more severe verbal deficit than perceptual deficit and imply that whereas the right hemisphere is functioning at a near normal level, the left hemisphere is performing below the normal range. Is was felt that A.A., like L.B., would be more likely to show right hemisphere speech than other available patients since, unlike the other patients, his minor hemisphere seemed to be able to perform its special functions adequately and normally. Since our interest was mainly in whether a normal, undamaged minor hemisphere might be capable of expressive language, our testing was focused on these two patients.

Procedures and observations

L.B. — Three separate subtests were utilized in attempting to elicit expressive language from the minor hemisphere of L.B.: first, two or three plastic letters, 1-1/2″ high, were presented to the left hand which was hidden from the subject's view by a screen. He was told that if the letters were arranged properly, they would spell a word, and that it was his task to put the letters in such an arrangement. The test procedure was demonstrated in free vision by the examiner and L.B. appeared to have no difficulty understanding the task. The test results with the left hand are presented in Table I. The responses were correct for all of the 6 sets of letters presented ($p < .001$). Following completion of the letter arrangement with the left hand, the subject was asked what word he had spelled. In all cases he was unable to say. Though the minor hemisphere could thus effect language expression manually through letter arrangement, the answer could not be expressed vocally, by either hemisphere.

TABLE I

Results of Letter Arrangement Test

Letters given	Word spelled
I,F	IF
A,C,N	CAN
B,O,Y	BOY
E,P,T	PET
B,Y	BY
O,S	SO

The subject was given two or three letters all at once in his left hand and was told to arrange them into a word.

In a second type of test he was presented with plastic letters which were already formed into words. His task was to feel the word and then either to say what it was or to write the word with a pencil held in the left hand, the hand still screened from view. On some trials he was asked only to write the word and then later was asked to verbalize it. On other trials he was first asked to name aloud the word felt, and then to write it. The results are presented in Table II. In no instance could he vocally designate the correct word unless he had written it first. Note particularly the word "pet." After feeling the word he was unable to express verbally what the word was, though he was then successful at printing it with the left hand. Immediately after he had completed printing the word he was able to say "pet."

It is evident from the results that the minor hemisphere was able to express language through control of the left hand, but not through control of the vocal apparatus. The successful vocalizations obtained

TABLE II

Written and Spoken Readouts of Words Presented Tactually to the Left Hand

Word presented	*S* said	Word written	*S* said
IF	don't know	IF	.....
SO	don't know	SO	.....
BY	don't know	BY	.....
CAN	TO	MAN	.....
HAT	.....	HAT	HAT
BOY	don't know	BOY	.....
PET	don't know	PET	PET
SOON	.....	SOON	SOON
FAT	.....	FAT	GOT
DAY	.....	DAY	O-A-A

in this test can be attributed to bilateral kinesthetic feedback that allowed the major hemisphere to discriminate what the left hand had written. In checking this, we found that when the examiner moved the passive left hand of the patient through similar words and numbers the subject was generally able to verbalize the given word or number. It is interesting that, whereas functionally the tactile system seems to have only a very weak ipsilateral projection in this patient, the projection of the kinesthetic system is bilaterally functional to such an extent that the major hemisphere can discriminate even fine hand and wrist movements of the left hand. It becomes important, accordingly, to control for hand movement in studies of minor hemisphere language function, since finger-writing of letters, numbers, words, or drawing of simple geometric shapes is a rapid and easy method available to the patients for cueing information into the major hemisphere.

A question might be raised as to why the above-hypothesized bilateral kinesthetic system was insufficient to allow vocal read-outs by L.B. in the spelling and tactual reading tasks. In these tasks letter discrimination was typically accomplished by runnnig the fingers over the letters in a circular motion or by discrete palpations of the letters, rather than by moving the fingers or hand in a motion corresponding with the letter configuration. In other words, letter discrimination seemed to be accomplished by tactile rather than by kinesthetic cues, thereby confining sensory information to the contralateral hemisphere.

In the third type of test, instead of word stimuli, a variety of household objects such as a ball, plastic key, miniature book, etc., were presented to the left hand, screened from sight, and L.B. was asked to write the names of the test items. It was consistently the case in these tests that only the first letter or two was correctly written. These letters were generally made by slow deliberate movements, with the pencil tightly grasped in the left hand. He would then either stop or, holding the pencil more naturally, add other incorrect letters. For example, he managed to print "C" when handed a cup and "S" when handed a spoon, but he could get no further. Figure 1 illustrates a sample response made with the left hand after a smoking pipe had been presented to the left hand for minor hemisphere identification. He first printed "PI," pressing down very hard with the pencil; after completing these first two letters, he stopped, and after a delay of a second or so, gripped the pencil in a much more relaxed manner and completed the word "Pencil." After another pause, he then scratched

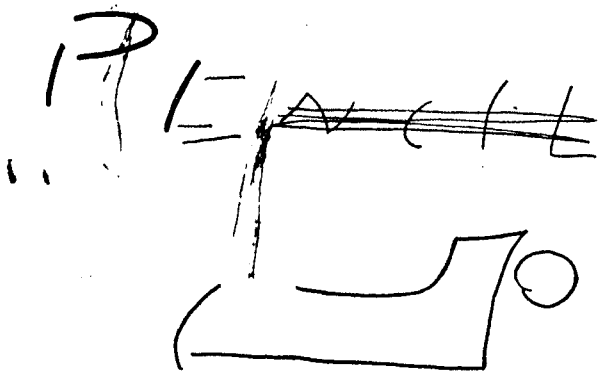


Fig. 1 — *Patient L.B.: Writing by left hand after it had felt a tobacco pipe.*

out the last four letters and stated vocally that he didn't know what the object was. He was asked at that point if he could draw a picture of the test object, still with his left hand out of sight behind a screen. His attempt to draw the answer is shown at the bottom of Figure 1.

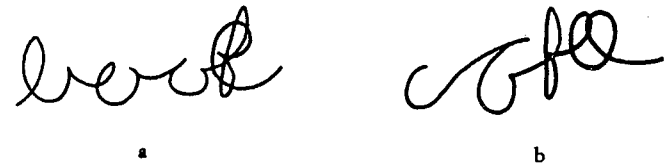
A.A. — In testing A.A. for minor hemisphere language the cues were presented visually, as earlier tests with this subject (Nebes and Sperry, in preparation) have shown that, due to compensation for early cortical injury, tactual information from A.A.'s left hand is not confined to his right hemisphere. In the present test A.A. was seated before an upright translucent screen with a space between the bottom of the screen and the table. Before each test sequence, all of the visual stimuli to be used were shown to the subject in free view and he was asked to identify them. These stimuli were then flashed tachistoscopically to either the right or left half visual field with both the order of stimuli and the alternation between fields of presentation randomized. After each trial, the subject placed his left hand beneath the screen where, out of sight, paper and pencil were available for writing the name of what he had seen. In all cases he spontaneously wrote his answers in script. When he had finished writing, he was asked to verbally identify the stimulus that had been flashed.

In the first task, 10 to 15 common short printed nouns (key, cup, cork, etc.) were the visual stimuli. Using his left hand, the

subject was able to write in script 12 of 39 printed nouns flashed onto his left visual field. On 10 of these occasions he then either could not name or misnamed the word he had just written. For example, in Figure 2a can be seen the word his left hand wrote when "book" was flashed in his left visual field. He claimed to have written "cup." The nouns for which he responded correctly in writing but subsequently misnamed in speech were "cup," "comb," "dog," "key," "eye" (twice), "book" (twice), "cat" (twice). When his written answer was incorrect it tended to be one of two or three words that he repeated over and over, such as "pen," or "cork." After writing an incorrect word to a left field presentation he always named aloud the word he had written, indicating that the incorrect replies were written by the major hemisphere, which then, of course, could name the word it had guessed. Words flashed to the right visual field were written correctly with the left hand 16 of 24 times, all of which were subsequently vocalized correctly.

When printed verbs instead of nouns were flashed, of 12 presentations to the left field two possibly correct words were written. In the first case the word was "lie"; A.A. wrote "li," stopped, added "n" and said "run." In the second case the word was "sit"; he wrote "si," stopped, added "mp" and said "jump." Both "jump" and "run" were words he knew to be included in the test series.

In a second task, A.A. was required to write with his left hand the names of common objects whose pictures were flashed to one or the other visual field. Most of the pictures were of objects, printed names of which had been used in the first task. Again before the test, A.A. was shown the stimuli with free vision and asked to name them. Of the 54 tachistoscopic presentations of pictures to the left field, on only two occasions did A.A. write the correct word and then fail to name it. In both cases the picture was of a cat greatly resembling a family pet. On the first occasion, after being asked to say what



a b

Fig. 2 — *Patient A.A.:* a, *Visual stimulus: "book"; verbal answer: "cup"* — b, *Visual stimulus: picture of cat; verbal answer: "bottle"*

he had written, he tried to peer over the screen. When prevented, he admitted he did not know. In the second case he wrote "cat," stopped, said "No, that's wrong," added two loops (Figure 2b) and then said "bottle." It appeared that on these two occasions the minor hemisphere had correctly written the name of a stimulus seen in the left visual field. In all other presentations to the left visual field he wrote an incorrect word and then said aloud the word he had written. He wrote "cat" incorrectly only once in the 54 presentations to the left field. The names of pictures shown to the right visual field were correctly written 19 of 19 times.

Discussion

It seems apparent from these results that the minor hemisphere has some capacity to express at least simple language through control of the left hand. A large part of the difficulty exhibited in expressing object names seems ascribable to interference effects at lower levels stemming from the prevailing tendency of the left hemisphere to dominate. In L.B.'s attempt to write "pipe," the major hemisphere appeared to take control of the left hand after the first letter or two, thus blocking completion of the word by the minor hemisphere. A.A.'s performance showed the same type of interference. Incorrect completions of words correctly started and subsequent naming of the incorrect word are clearly indicative of intervention by the major hemisphere.

The fact that writing was more difficult in both subjects for objects or for pictures of objects than it was for words shows that, in addition to left hemisphere interference, there is also an intrinsic language limitation in the right hemisphere. When a printed word, instead of an object, was presented, the written response was much better. It should, however, be kept in mind that in the letter arrangement test, in which the possibility of left hemisphere interference was at a minimum, the performance was much superior. Apparently the active sensory exploration combined with motor control of the hand serves to keep the minor hemisphere in command.

It appeared that the major hemisphere never relinquished control of the vocal apparatus, and we attribute all accurate vocalizations to the left hemisphere which received left side stimulus information through an ipsilateral kinesthetic projection. Our results, taken in

conjunction with Smith's (1966) finding on a case of left hemispherectomy, suggest that the minor hemisphere could probably talk more that it does, were it not for the grip which the major hemisphere maintains over the motor channels for speech. It was not entirely a matter of the right hemisphere's inability to think of words, but was also a matter of the inability to successfully compete with the left hemisphere's control of motor mechanisms for language expression. It should be remembered that the poor command over motor channels no doubt results in part from a limited intrinsic capacity. We conclude this from the fact that the minor hemisphere has no difficulty in gaining control of the left hand when drawing instead of writing, and also from the fact that writing of nouns was much easier than writing of verbs. The differences between drawing of pictures and writing of words or between writing of nouns and writing of verbs reside not in the varying degrees of motor control required, but rather in differing central mechanisms.

Our results suggest that though there are two aspects of language expression — central conceptual dominance and peripheral motor dominance — there is a fairly direct relationship between the two. When a hemisphere is intrinsically better equipped to handle some task, it is also easier for that hemisphere to dominate the motor pathways. This relationship would suggest that the minor hemisphere would be motor dominant for tasks in which it is superior. Levy, Trevarthen and Sperry (in preparation) have recently confirmed this hypothesis in finding that when tachistoscopic non-verbal, visual stimuli are presented to both hemispheres, it is the minor hemisphere which dominates the motor mechanisms in selectively pointing to the one of an array of stimuli which had been seen by the minor hemisphere.

Summary

The ability of the disconnected minor hemisphere in two commissurotomy patients to express language was investigated. It was found that words could be expressed via left hand motor mechanisms when stimulus input was confined to the right hemisphere, either by arranging tactually perceivable plastic letters in proper sequence to spell a word or by printing or writing while the left hand was hidden from view. Techniques which minimized possible interference from the major hemisphere resulted in better performance than when such interference was possible, suggesting that at least part of the minor hemisphere's linguistic deficiences is due

to the major hemisphere's dominance over the motor mechanisms for language expression. However, the minor hemisphere also suffers from an intrinsic limitation in linguistic processing as evidenced by its inferiority in writing words as compared with drawing pictures and its inferiority in writing verbs as compared with writing nouns. Our results suggest that though there are two aspects of language expression — central conceptual dominance and peripheral motor dominance — there is a fairly direct relationship between the two. When a hemisphere is intrinsically better equipped to handle some task, its is also easier for that hemisphere to dominate motor pathways.

References

Bogen, J. E., Fisher, E. D., and Vogel, P. J. (1965) *Cerebral commissurotomy: A second case report*, "J. Am. med. Ass.," *194*, 1328-1329.

Gazzaniga, M. S., Bogen, J. E., and Sperry, R. W. (1963) *Laterality effects in somesthesis following cerebral commissurotomy in man*, "Neuropsychologia," *1*, 209-215.

—, and Sperry, R. W. (1967) *Language after section of the cerebral commissures*, "Brain," *90*, 131-148.

—, Bogen, J. E., and Sperry, R. W. (1967) *Dyspraxia following division of the cerebral hemispheres*, "Arch. Neurol.," *16*, 606-612.

Geschwind, N. (1965) *Disconnexion syndromes in animals and man*, "Brain," *88*, 237-294.

Gordon, H. W., and Sperry, R. W. (1969) *Lateralization of olfactory perception in the surgically separated hemispheres of man*, "Neuropsychologia," *7*, 111-120.

Levy, J., Trevarthen, C., and Sperry, R. M., *Perception of bilateral chimeric figures following hemispheric deconnection* (in preparation).

Nebes, R. D., and Sperry, R. W., *Hemispheric deconnection syndrome with cerebral injury in the dominant arm area* (in preparation).

Smith, A. J. (1966) *Speech and other functions after left (dominant) hemispherectomy*, "J. Neurol. Neurosurg. Psychiat.," *29*, 467-417.

Sperry, R. W., and Gazzaniga, M. S. (1967) *Language following surgical disconnection of the hemispheres*, in Brain Mechanisms Underlying Speech and Language, ed. by R. L. Darley, Grune and Stratton, New York.

J. Levy, Ph. D., Department of Psychology, University of Colorado, Boulder, Colorado 80302, U.S.A.
R. D. Nebes, Ph. D., Duke University Medical Center, Duke University, Durham, North Carolina 27706, U.S.A.
R. W. Sperry, Ph. D., Division of Biology, California Institute of Technology, Pasadena, California 91109, U.S.A.