62

Article abstract

Preliminary psychologic testing was carried out on four patients who had undergone surgical sectioning of a portion or all of the corpus callosum and anterior commissure as a treatment for uncontrollable seizures. Results confirm earlier findings indicating the importance of the forebrain commissures in the interhemispheric exchange of a variety of sensory and motor information, and demonstrate that particular portions of the commissural system are responsible for transferring the information of specific sensory modalities. The patients also showed surprising abilities in performing complex tasks assumed to require integration of information from both hemispheres.

Psychologic and neurologic consequences of partial and complete cerebral commissurotomy

M. S. GAZZANIGA, Ph.D., G. L. RISSE, M.S., S. P. SPRINGER, Ph.D., E. CLARK, A.B., and D. H. WILSON, M.D.

In recent years the psychologic and neurologic consequences of sectioning the neocortical commissures have been extensively studied in man.[1-6] These results have shown that a dramatic breakdown occurs in the interhemispheric exchange of visual, tactual, olfactory, and motor information after complete sectioning of the cerebral commissures. In addition, various unique psychologic properties of the two separated cerebral hemispheres have been extensively described and studied. The left hemisphere has been found to be vastly superior to the right in processes involving speech and language, while a variety of visual-spatial tasks are performed with greater accuracy and proficiency in the right hemisphere.

The present paper reports on a variety of preliminary studies done on a new series of patients, operated on by D. H. Wilson of Dartmouth Medical School in an effort to prevent the interhemispheric spread of seizure activity. Unlike the original Bogen series,[7] this group includes patients with both complete and partial sectioning of the forebrain commissures. In addition, the general operative approach used to section the commissures differs from that used in the Bogen series.

From the Department of Psychology, State University of New York, Stony Brook.

This study was supported in part by USPHS grant 17883-04 awarded to M. S. Gazzaniga.

Parts of this report were presented at the twenty-sixth annual meeting of the American Academy of Neurology, San Francisco, 1974.

Received for publication August 12, 1974.

Dr. Gazzaniga's address is Department of Psychology, State University of New York at Stony Brook, Stony Brook, NY 11794.

Methods. *Description of patients.* J. H. is a 26-year-old man who had complete sectioning of the corpus callosum and anterior commissure.

T. O., a 10-year-old boy, also had a complete commissurotomy, including sectioning of the anterior commissure, but had suffered from early hemiparesis of the left side and has a grossly abnormal right hemisphere.

J. K. N., an 18-year-old youth, originally was assumed to have the entire callosum sectioned but subsequent psychologic testing (described below) has strongly suggested that some fibers of the splenium remain intact.

J. K. T. is a 28-year-old man who underwent sectioning of the anterior commissure and anterior one-third of the callosum only.

In some of the tests that follow, data from a patient of another series[8] will be included. This patient had only the splenium sectioned.

Procedure. Most of the testing procedures used in these studies were developed earlier for the specific testing of commissure-sectioned patients.[5] Tachistoscopic

Reprinted from NEUROLOGY, Minneapolis, January 1975, Vol. 25, No. 1

projection of stimuli in one visual field or the other was utilized to effect lateralization of visual information to one hemisphere. Auditory testing was carried out with the use of carefully prepared dichotic tapes in which the patient received two different messages simultaneously, one message to each ear. In addition, a variety of pictures and objects were used for a number of special tests designed to assess the integrated functions of the two hemispheres.

All patients were tested in a specially designed house trailer converted for neuropsychologic examination (figure 1). The trailer was driven to the respective patient's home and all testing was carried out under normal laboratory control conditions.

Results. *Vision.* A patient who has undergone complete sectioning of the corpus callosum and anterior commissure is expected to show no interhemispheric exchange of visual information. In tachistoscopic presentation of words, objects, and geometrical figures to visual half fields, T. O. showed a complete inability to verbally describe stimuli appearing in the left visual field. J. H. was totally unable to describe words flashed to the right hemisphere but could identify a total of six objects (on colored slides) from a list of 20 presented twice to the left visual field. J. K. N. demonstrated complete transfer of all visual information, suggesting that contrary to the original surgical report, some fibers of the splenium remain intact. This patient, as described below, did not show interhemispheric transfer of tactual information, thereby confirming the notion that portions left unsectioned were confined to more posterior regions of the callosum. J. K. T. showed a complete transfer of visual information under all test conditions.

Stereognosis. T. O. and J. K. N. were unable to discriminate objects placed in the left hand but could easily name those items placed in the right hand. J. H. surprisingly performed at about 50 percent accuracy, correctly identifying half of the objects placed in his left hand, but results to date do not eliminate the possibility of cross-cuing strategies in this patient. Subsequent retrieval of objects placed in the left hand was managed by patients J. H. and J. K. N., but was performed poorly by T. O., probably because of the overall inferior right hemisphere capacity resulting from his infantile hemiparesis. J. K. N. also showed left hand tactile recognition of objects flashed in the right visual field, further evidence of his ability to transfer visual information. J. K. T. could easily identify all objects placed in either hand.

Audition. Previous research has shown that left hemisphere dominant patients whose sections include the region anterior to the splenium and posterior to the first one-third of the corpus callosum are unable to report any material presented to the left ear when the stimuli are dichotically presented consonant vowel syllables.[9] This finding held not only for verbal report but also for a manual pointing response with either the left or right hand.

Table 1 shows the data obtained when the dichotic stimulus materials were composed of animal names, such as "doggy" and "horsey." In the first task, subjects were asked to report which of two dichotically presented names was loudest and clearest. All patients showed a very strong right ear advantage with this procedure. When asked to report both stimuli, however, J. H. and J. K. N. were able to verbally report a substantial number of left ear items. Similar results were obtained with digits as stimuli. These findings then are at variance with the data obtained with dichotically presented consonant vowel

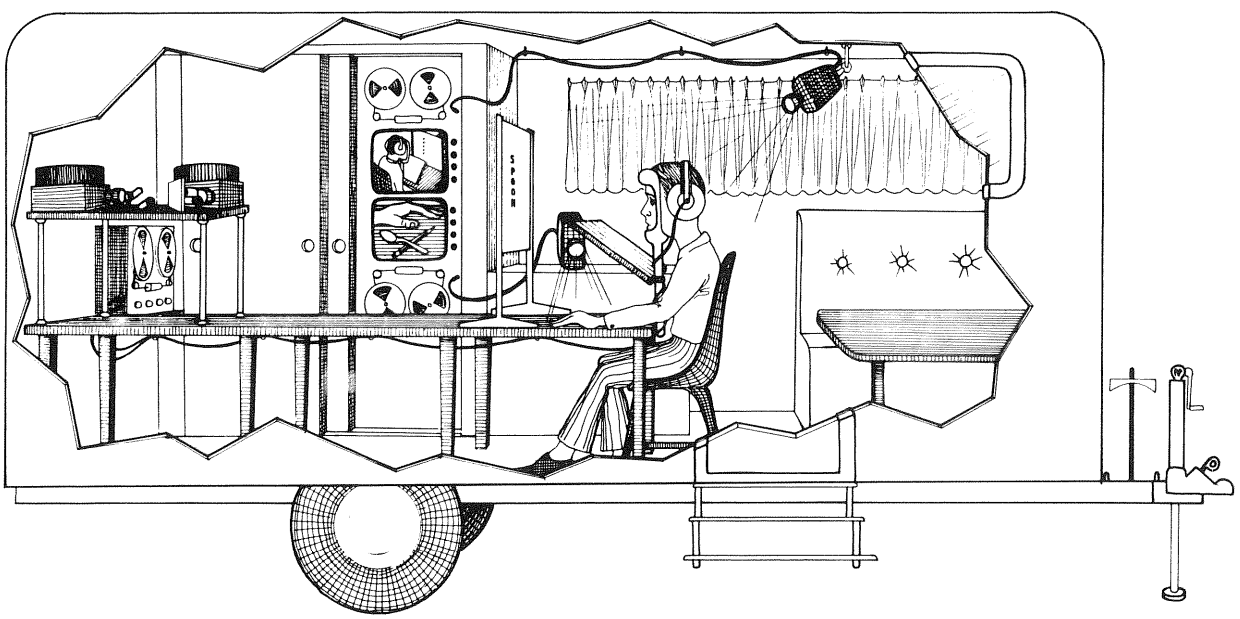

Figure 1. Neuropsychologic testing unit allowing for lateralized presentation of visual stimuli and convenient placement of all testing equipment.

Table 1. Dichotic testing using simultaneously presented animal names

Patient	Reports loudest and clearest	Reports two words
J.K.T.	27/28 right ear	
J.K.N.	25/28 right ear	17/21 both ears
T.O.	28/28 right ear	
J.H.	26/28 right ear	12/21 both ears

When patients were told to report the loudest and clearest word, there was a strong right ear effect. When asked to report two words, however, the two patients tested demonstrated a clear ability to name left ear stimuli.

syllables. All types of stimuli were easily identified when they were presented one at a time to each ear alone. These results are consistent with previous work with both normal and callosum-sectioned subjects showing ear asymmetries only under conditions of dichotic presentation.

Olfaction. In this test, J. H., who had a complete commissure section, failed at interhemispheric transfer of olfactory information, which is consistent with the findings of Gordon and Sperry.[10] J. K. T. showed an unstable performance on this test. In one session he behaved as though no olfactory information was being interhemispherically communicated, while in other tests he behaved normally.

Special testing. A number of tests for the purpose of assessing the integrated functions of the right and left hemispheres were administered.

Wisconsin Card Sorting Test. This test has been shown to be highly sensitive to frontal lobe damage in both the left and right hemispheres,[11] but the possible role of the cerebral commissures in carrying out such a task has not been assessed. The test was administered to all four patients, with the order of presentation of categories being color, form, number, and color. Essentially normal scores were achieved by J. K. T. and T. O. (table 2). J. K. N. showed a total of 74 errors, 44 of them of the perseverative type. However, most of his errors occurred on the fourth shift, and if that category is excluded, his performance falls within the normal range. J. H. was unable to complete the test because of fatigue, but in the three categories achieved, he showed as many nonperserverative as perseverative errors.

Imagery construction. In this test, patients were tested for recall of two lists of 10 paired-associate nouns. All words used were equated for length, frequency of occurrence, and imagery value.[11] For the first set, each word pair was read to the patient simultaneously with a visual presentation of the word on a card. The patient was told simply that he would be asked later to recall the second member of each pair after hearing the first. No suggestion was offered as to how he might remember the pairs. After a patient was tested for recall of the first list, he then was offered a second set, but this time he was instructed to form a "picture in his mind" of the two items interacting in some unusual or amusing way. It can be

Table 2. Performance on the Wisconsin card sorting task, based on four shifts: color, form, number, color

Patient	Lesion	Categories achieved	Total errors	Persev-erative	Non-persev-erative
J.K.T.	A.C., ant. 1/3 C.C.	4	6	2	4
T.O.	C.C., A.C. early lesion	4	15	3	12
J.K.N.	A.C., C.C. Splenium intact	4	74	44	27
J.H.	A.C., C.C.	3	37	19	18

A.C. = anterior commissure, C.C. = corpus callosum.

Table 3. Recall of word pairs with and without imagery instruction

Patient	Lesion	No memory instructions (No. of word pairs in 10)	Imagery instruction (No. in 10)
J.K.T.	A.C., ant. 1/3 C.C.	2/10	6/10
J.K.N.	A.C., C.C. Splenium intact	1/10	7/10
J.H.	A.C., C.C.	0/10	0/10
E.G.	Splenium	2/10	6/10

seen from table 3 that the three patients with partial commissurotomy all showed considerable improvement in recalling word pairs when instructed to use imagery, but that J. H., with a complete commissurotomy, did not benefit from imagery instruction. The failure of this patient to recall the word pairs is not believed to be the result of a short-term memory deficit per se, since he did demonstrate a normal digit span of five forward and four backward.

Anagram solving. Patients were asked to solve three, four, and five-letter anagrams presented either as a typed word on a card or as individual cut-out letters that could be rearranged by the patient. Although the time required to solve each anagram varied greatly, all patients easily solved the three-letter and four-letter anagrams under both conditions of presentation. Some difficulty was encountered on the five-letter anagrams by J. K. N. These sets were not administered to T. O.

Facial description. A series of 15 faces depicting common emotional states were presented with a choice of four descriptive adjectives for each picture (figure 2). The patients were asked to circle the word that best described the face. J. K. N. and T. O. both achieved a score of eight correct, suggesting some difficulty in describing emotion. However, particularly in the case of T. O., a lack of understanding of some adjectives probably impaired performance. J. H. correctly described 11 of the 15 faces,

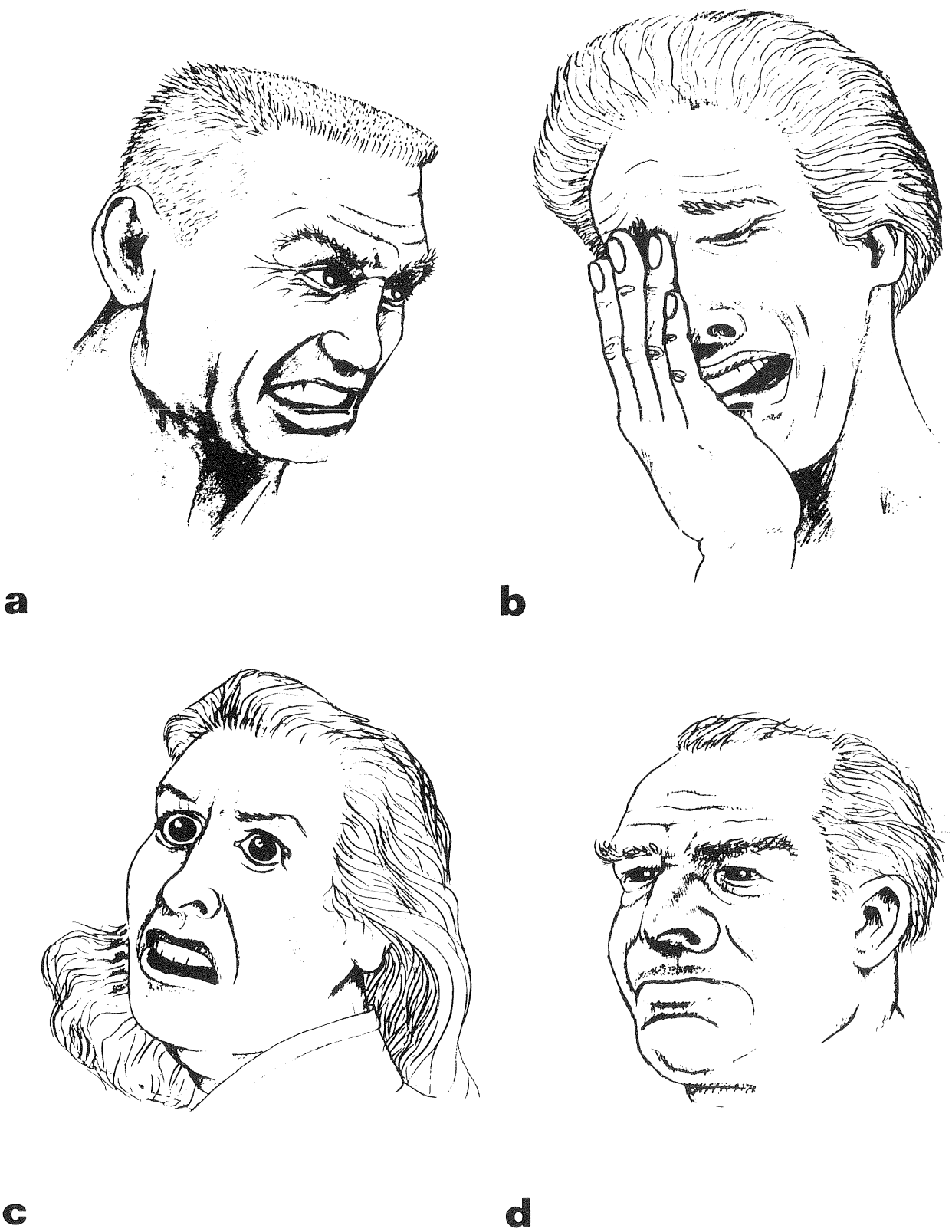

Figure 2. "Emotional" faces from a series presented to patients for verbal description. Choices offered were (a) helpless, content, shy, enraged; (b) angry, joyous, grievous, pained; (c) surprised, horrified, disgusted, satisfied; (d) jovial, bored, stubborn, pleased. Correct choices are underlined.

with several of his errors being quite obvious. For example, he described the "depressed" face as "happy" and the "elated" face as "defiant." The possibility that the patients simply chose the most familiar words has been ruled out, because although the adjectives were not equated for frequency, the patients often responded correctly when the correct choice was the least frequent of the four. J. K. T. made only one error in describing the faces.

Song recognition. In this test, the patients listened to a tape recording of 12 very common tunes usually learned in childhood and nine less common ones of a more contemporary variety, played on the piano with no words available, and they were asked simply to give the titles of the songs. With the exception of T. O., all patients were able to name most common songs easily, as well as many of the less common ones. A patient often would follow along saying the words to a song until he reached the title line and then would call out the title. T. O. was unable to name most songs but stated that several of the tunes were familiar. Again, the young age of this patient can be offered as a partial explanation of the deficit.

Discussion. The foregoing results support the general conclusions made on earlier patients that the cerebral commissures are critically important in the interhemispheric exchange of many forms of information processed within the two cerebral hemispheres of the human brain. In addition, these results are consistent with the theory that fibers of specific portions of the commissural system transfer particular kinds of information. Partial commissurotomy (particularly of more posterior portions) appears to result in the breakdown of specific sensory modalities. A patient with only fibers of the splenium left unsectioned can transfer visual but not tactile information, while another patient in whom the splenium was the only portion sectioned shows an opposite result.[8]

Such relationships do not seem surprising when the cortical areas subserving visual and somatosensory functions are considered. Fibers traversing the anterior portions of the commissural system, including the rostrum of the corpus callosum and the anterior commissure, have not been shown to project to primary sensory cortex, with the possible exception of some olfactory fibers; indeed, it is the specific functions of these anterior pathways connecting portions of the temporal and frontal lobes that remain difficult to define. It was supposed that a breakdown in the transfer of olfactory information, as previously reported by Gordon and Sperry[10] with fully commissurotomized patients, may be a result of interruption of the anterior pathways, perhaps exclusively fibers of the anterior commissure. While our patient with a complete section did fail at olfactory transfer, we were unable to demonstrate clearly the decrement in the patient with only anterior portions sectioned.

The auditory data obtained under conditions of dichotic testing are somewhat confusing. Although a considerable portion of incoming auditory information is known to project ipsilaterally, the "competitive" situation introduced by the simultaneous presentation of verbal stimuli in the dichotic task has quite consistently shown superiority of the ear contralateral to the dominant hemisphere. The ability of these patients to repeat animal names presented to the left ear in the dichotic situation, while showing the usual suppression of left ear stimuli when presented with consonant vowel syllables,[9] probably reflects basic differences in the stimuli themselves. The animal names may be easier to discriminate because of their familiarity. Conversely, the consonant vowel syllables, although simple in construction, are unfamiliar as independent units and may therefore be more difficult to recognize and extract from the weaker ipsilateral projections.

While interhemispheric transfer of some primary sensory information has been shown to be dependent on the integrity of specific portions of the commissure system, other more secondary forms of processed information seem to transfer readily across any available pathway.[12] Thus, partially sectioned patients show no difficulty in translating word pairs into images regardless of which fiber pathways remain open. Perhaps the initial decoding of primary sensory input, such as that which must occur in response to linguistic stimuli, renders the information more "transferable" than its original form.

Transfer of information between the hemispheres does not appear to be necessary for normal performance on the Wisconsin Card Sorting Test, suggesting that cognitive processes involved in this task can occur independently in either hemisphere.

Clearly the most puzzling finding is the apparent ability of the fully commissurotomized patients to "integrate" functions that have been ascribed to opposite hemispheres. Although patient J. H. did fail in imagery construction, he showed a surprising ability on other integrative tasks. The anagram test was designed to be a verbal puzzle with a spatial component, the act of either mentally or tactually rearranging letters to form a recognizable word. The fact that this task was easily performed by the fully commissurotomized patients suggests that either the task did not actually involve a spatial component, or whatever spatial ability was required was easily accommodated by the speech hemisphere.

Although no patient attained a perfect score in verbally describing the "emotional" faces, the results are not indicative of the decrement that might be expected if facial recognition and the appreciation of emotional expressions were predominantly right hemisphere functions.

Finally, it is somewhat surprising that the fully commissurotomized patient has no difficulty putting words to music and presenting titles for a wide variety of songs. It is worth noting that the apparent process involved in naming songs for both the complete and partially sectioned patients appears to be essentially identical to that of the normal person, that is, at first perhaps humming along with the tune, then saying the words, and finally calling out the title, usually when it appears in the words of the song.

In these "integrative" tests, all stimuli were presented simultaneously to both hemispheres, allowing for maximal utilization of cross-cuing strategies in problem solving.

Nevertheless, it seems likely that some interhemispheric comparison and exchange of verbal and nonverbal information should be necessary to carry out such complex tasks. How does this exchange occur? As mentioned earlier, in the case of the partially sectioned individual, whatever commissural fibers remain intact may be sufficient to transfer these preprocessed forms of information. This cannot, however, explain the performance of patients with complete sections. Additional testing is clearly called for, particularly in the case of J. H., whose results are somewhat inconclusive given the extent of his lesion. However, the present data clearly suggest that the integrative abilities of a single hemisphere have been underestimated in attempts to demonstrate asymmetry of functions within the cerebral hemispheres.[13] Clearly the left hemisphere must have some ability to appreciate music, recognize facial expression, and the like, or verbal abilities far beyond those currently attributed to the right hemisphere must be recognized.

REFERENCES

1. Gazzaniga MS, Bogen JE, Sperry RW: Some functional effects of sectioning the cerebral commissures in man. Proc Natl Acad Sci 48:1765-1769, 1962
2. Gazzaniga MS, Bogen JE, Sperry RW: Observations on visual perception after disconnection of the cerebral hemispheres in man. Brain 88:221, 1965
3. Gazzaniga MS, Bogen JE, Sperry RW: Dyspraxia following division of the cerebral commissures in man. Arch Neurol 16:606-612, 1967
4. Gazzaniga MS, Sperry RW: Language after section of the cerebral commissures. Brain 90:131-148, 1967
5. Gazzaniga MS: The Bisected Brain. New York, Appleton, Century, Crofts, 1970
6. Sperry RW, Gazzaniga MS, Bogen JE: Interhemispheric relationships: The neocortical commissures; syndromes of hemisphere disconnection. In Vinken PJ, Bruyn GW (Editors): Handbook of Clinical Neurology. Amsterdam, North-Holland Publishing Company, 1969, vol 4, pp 273-290
7. Bogen JE: Neurological analysis of split-brain patients. To appear in Michel F (Editor): The Syndrome of the Corpus Callosum in Man. France, 1974
8. Gazzaniga MS, Freedman H: Observations on visual processes after posterior callosal section. Neurology (Minneap) 23:1126-1130, 1973
9. Springer S, Gazzaniga MS: Dichotic testing of partial and complete split-brain patients. Neuropsychologia, in press.
10. Gordon HW, Sperry RW: Lateralization of olfactory perception in the surgically separated hemispheres of man. Neuropsychologia 7:111-120, 1968
11. Milner B: Some effects of frontal lobectomy in man: In Warren JM, Akert K (Editors): The Frontal Granular Cortex and Behavior. New York, McGraw-Hill Book Company, 1964
12. Gazzaniga MS: Partial commissurotomy and cerebral localization of function. Otfrid Foerster Symposium, Kolin, Germany, September, 1973
13. Gazzaniga MS: Beyond lateralization. To appear in Michel F (Editor): The Syndrome of the Corpus Callosum in Man. France, 1974