Interhemispheric relationships: the neocortical commissures; syndromes of hemisphere disconnection

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Until a few years ago, prevailing views regarding the syndrome of the corpus callosum in man were based very largely on the studies of Akelaitis and his co-workers (Akelaitis et al. 1942; Akelaitis 1944). Using a wide variety of tests Akelaitis examined a series of more than two dozen patients with partial and complete surgical sections of the corpus callosum and anterior commissure and was unable to find any consistent neurological or psychological dysfunctions that could be reliably attributed to the commissural sections. Symptoms such as unilateral asterognosis, agraphia, ideomotor apraxia (Sweet 1941), as well as apathy, amnesia, personality changes and related effects, that earlier had been ascribed to callosal lesions (Alpers and Grant 1931) seemed according to be more properly explained in terms of the extracallosal cerebral damage that commonly accompanies lesions in the commissures. These Akelaitis reports in combination with confirmatory observations on absence of symptoms after callosum section in animals established the general doctrine of the 1940’s and 1950’s in which it was believed that behavioral deficits seen in connection with callosal lesions are best ascribed to associated brain damage (Bremer et al. 1956). Meanwhile, the discrepancy between the enormous size and strategic position of the corpus callosum on the one hand and the observed lack of any important functional disturbance following its complete surgical section on the other remained during this period one of the more puzzling enigmas of neurology.

In a subsequent series of so-called ‘split-brain’ animal studies begun in the 1950’s (Myers 1961; Sperry 1961) it became possible through utilization of various experimental devices and controls to eliminate some of the ambiguities in the earlier evidence and to find at last a considerable number of important functions mediated by the neocortical commissures. In brief these ‘split-brain’ studies, conducted mainly with cats and monkeys, showed that the neocortical commissures are necessary for the interhemispheric transfer of learning and memory and also for the interhemispheric integration of many sensory and motor functions that involved the left and right hands or paws, and the left and right halves of the visual field. By 1960 the broader features of the cerebral deconnexion, or ‘split-brain’ syndrome, were well established with respect to subhuman mammals.

Not long thereafter comparable symptoms were observed in a human patient with cerebral

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neoplasm and callosal infarction (Geschwind 1962; Geschwind and Kaplan 1962) and in another patient with surgical section of the forebrain commissures (Bogen and Vogel 1962; Gazzaianza et al. 1963). Bolstered by these confirmatory observations in man, the emerging picture of the connectional role of the neuronomatous commissures seemed sufficiently validated that it might be used to settle at long last some of the many confusing contradictions in the clinical literature (Geschwind 1963). A return to some of the older views of Dejerine, Liehmann, and others seemed to be indicated at this point along with a corresponding reexamination of the Akahatai reports. It shortly became evident, however, that the long and complex controversy of the corpus callosum was not to be settled quite so quickly and that further significant swings in the pendulum of opinion were yet to come. During the past several years, further observation of additional human patients with surgical section of the forebrain commissures has brought a mass of new evidence and with it a further shift in the theoretical outlook on the callosum (Gazzaniga et al. 1965, 1967; Gazzaniga and Sperry 1967; Gazzaniga 1967; Sperry 1967; Sperry and Gazzaniga 1967).

The most recent evidence comes from the study of a series of patients of Dr. Philip Vogel in whom surgical section of the commissures was carried out as a therapeutic measure in various disorders not controlled by medication (Bogen and Vogel 1962; Bogen et al. 1965). All of these patients had undergone, in a single operation, complete transection of the corpus callosum, the anterior commissure and the hippocampal commissure plus, in several individuals, the massa intermedia. The same operation had been carried out previously in many dozens of monkeys the results of which, along with the observations on callosal section in man, indicated that the behavioral outcome should not be seriously incapacitating (Sperry 1961). There was reason, further, to favor the single complete section over partial sections performed serially. It was hoped that this surgery might help to confine the epileptic seizures to one side and to preserve consciousness during an attack, that it might enable the patient to take precautionary or control measures at the onset of a seizure, and that the severity and duration of the attacks might be reduced by a remission of the commissural contribution to the generalized phase, and especially during true epileptiform.

When the surgery proved effective in eliminating generalized convulsions in the first two patients it was subsequently employed in additional cases most of whom are still too recent to evaluate. Although the therapeutic effect has been mixed among the later patients of the series, the outlook continues to hold promise for selected severe cases.

Included among the earlier patients of the series were two individuals (N.G. and L.B. whom the postaural course was particularly smooth, postoperative functions relatively unimpaired, and in whom the extracallosal brain damage seemed to be at a minimum for the age and sex of the patient. In the case history described below on the supposition that they come closest to a pure hemisphere disconnection syndrome.

In both cases, however, there is presumed to have been some epileptogenic cerebral damage stemming from birth injuries that may possibly include, especially at the lateral specialization in cerebral function. It is of the special cause given their syndrome in the present account, further details of the earlier cases histories of these two select patients are here provided as follows:

Case history N. G.: N. G. was born June 29, 1917. In the sixth postnatal month, was in an incoherent state for some weeks, and then leaving the hospital weight.

Case history N. G. and L. B.: As described in a previous report (Bogen et al. 1967) and was admitted for cerebral commissural surgery. She was always right-handed and right-sided functional progression of extracallosal cerebral damage. In contrast to the cerebral disconnection syndrome as recently defined, these cases are able to, for example, write meaningful material and perform written calculations with the subordinate hand. They draw with one hand the shapes of objects presented to the other hand or opposite half visual field. They locate with either hand points of tactile stimulation on the opposite half of the body. They carry out verbal commands with the subordinate hand; and they are not "word-blind" and "word-deaf" in the disconnected minor hemisphere. Whereas these and related observations tend to swing the over-all syndrome picture significantly back in the Akahatai direction, there nevertheless remain certain important contradictions making our current interpretation described below a rather heterogeneous composite of earlier opinion. The general syndrome picture is still developing and it would be premature even now to attempt global value judgments regarding historical developments and contributions on the controversial issues involved.

Disconnection symptoms

The most remarkable effect of sectioning the cerebral commissures continues to be the apparent lack of change with respect to ordinary behavior. The least affected of Vogel's patients, in whom complete section of the entire corpus callosum and anterior commissure was virtually visualized during surgery, exhibit no gross alterations of personality, intellect or overt behavior two years after operation. Individuals showed are somewhat altered in preoperative period, and during the fifth year undisciplined and well oriented. In the first three years after operation, he had three generalized convulsions which the left-sided convulsions at 8:18, 12:18, and has since been making considerable progress in all subjects except mathematics.

There have been many reports that the difference between the sensory input and that as seen three years ago would seem to reflect the differences symptoms obtained with clean surgical sections per se, and those obtained with commissural lesions accompanied by additional and associative functions.

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also to have its own conscious sphere for sensation, perception, ideation and other mental activities and the whole inner realm of gnomic experience of the one is cut off from the corresponding experiences of the other hemisphere—with only a few exceptions as outlined below.

For the sake of unity and convenience of description, the various disconnection symptoms that have been demonstrated to date are outlined below with specific reference where possible to a general testing unit that we have used regularly for examining these patients illustrated in Fig. 1. The subject is seated at a table on which is mounted an adjustable shield that protects the subject from seeing his hands or those of the other or both hemispheres as objects projected or otherwise engaged in the testing. The subject is also served to hold a white glass viewing screen in the left and right halves of the subject's visual field using a remote-controlled projector equipped with a mechanical shutter for quick-flash tachistoscopic presentation.

Fig. 1. Top and side views of basic testing unit used extensively to examine commissurotomized patients. Visual stimuli are back projected at 1/10 sec. or less onto translucent white screen with subject's motor responses to objects presented visually in the left and right visual fields. When a pair of objects or images is presented simultaneously, one to the left and one to the right visual field, and the subject is told to retrieve a matching object by touch with the left hand, the right hand picks out only the object pictured in the left visual field. If, before he can look at it, the person is asked what he has
chosen with the left hand, he responds with the name of the object seen in the other – the right half-field (Fig. 2). This occurs even with gross discrepancies between the two objects. The right-left division of the visual field, as indicated in such tests, is abrupt at the midline without noticeable central sparing or overlap. Letters, dots or lines as close as one degree to the central fixation point on the left side are not included in the verbalized responses covering the right half-field and the converse is true of the manual readiness for the left half-field.

A large variety of such visual tests point to the conclusion that in the absence of the commissures, things seen in the left and right halves of the visual field are processed separately in the right and left hemispheres respectively. The normal interaction between elements within each half-field is preserved, but visual integration across the midline is eliminated. Each of the separated hemispheres has its own visual sensations, perceptions, associated concepts and short- and long-term memories; the gnostic visual experiences of the one seem to have no direct contact with those of the other. In many ways it is as if two separate brains were viewing the left and right halves of the visual field, only one of which is able to communicate what it sees through speech or writing.

From the foregoing it seems evident that the commissures in the normal, intact condition subserve a large variety of visual functions, sensory-motor, sensory-motor, and associative in nature. One of the most critical of these from the clinical standpoint is the integration of the visual functions of the minor hemisphere with the major hemisphere. The visual deficits resulting from cerebral commissurotomy do not cause much difficulty under ordinary conditions apparently because scanning movements of the eyes bring the contents of the left half of the visual world into the right visual field. Vision is further unified by the conjunctive control of the eyes from each hemisphere along with other factors that tend to make each hemisphere view and attend to the same material all the time. Except in artificial testing situations, in which much care is taken in giving verbal instructions, the patient usually denies even the presence of the left hand stimulus while describing that in the right hand. The major system appears to exclude the competing ipsilateral activity within the same hemisphere.

When an object is placed in the left hand, the subject tries to guess what it is, calling upon information for whatever comes to mind and using whatever clues are available. Auditory cues in particular must be carefully guarded against. Sounds of the moving fingers or finger nails, or movement of a ring against the surface of the test object or brushing of the object over a table surface may be sufficient to give the answer to the dominant hemisphere, especially where a small number of known objects is involved. Thus all such indirect sensory avenues to the dominant hemisphere were controlled, the pressing patients were unable to name or describe objects or any other complex stimuli patterns presented to the left hand. Why this symptom is not seen in the Akalasian results is not clear. Significant control of indirect cues might be an explanation.

It could be shown in respect to the left hand that for the visual field, that the minor hemisphere can nevertheless perceive, recognize, name, and remember those same test items which the patient says he cannot feel. The patient can often demonstrate, by appropriate manipulation of a given test item such as a pencil, a toy pistol, a cigarette, fork, etc., even though the attempt to name these same objects by speech or writing remains purely fortuitous. The patient, who has been well trained in the use of a given test item such as a pencil, can then be surprised by blind palpation when placed in random position out of sight among a collection of other items. This is possible with delays imposed of several minutes to an hour or longer, i.e., the minor speechless hemisphere learns to recognize an object and retains the concept over a delay period well beyond the maximum level for delayed response in subhuman primates.

The most conspicuous symptom in the minimalistic sphere is this apparent amnesia in the left hand that proves to be more exactly a unilateral cerebral projection in the somesthetic parietal area. This may be attributed to the block in communication between the left hemispheric centers for speech and writing and those for the left hand in the right hemisphere. Other deficits, not involving speech, are also demonstrable. If the fingers of the left hand are touched lightly on the tip, middle or basal segment or at its between points, the patient, with vision excluded, can easily locate the stimulated point with the tip of the thumb of the same hand. The normal person can also indicate with the opposite right thumb the corresponding mirror point in the opposite hand. Nearly all such cross-localization between the hands breaks down in the commissurotomized patient who is usually unable to cross-localize without vision even the correct finger, much less points within a finger. Similarly a posture imposed on thumb and fingers of one hand by the examiner cannot be copied in the opposite hand.

The lack of cross-integration for topogonosis within the hand does not apply uniformly to the entire cutaneous half-field of the body. In the head and neck regions little or no breakdown of cross-integration is apparent owing presumably to strong bilateral representation of the head and neck in each hemisphere. Somatic stimuli on the left as well as on the right side of the face are located, discriminated, and described verbally in speech or in writing. There is no unusual difficulty in naming objects placed in the mouth.

Over most of the torso and limbs, excluding the hands and feet, the situation tends to be intermediate. While verbal report is fairly good for localization on the left side, it is poor for even simple determinations of modality and position sense. More complex and refined discriminations, like the interpretation of skin writing or perception of shapes, which in the normal person exhibit cross-communication from left to right side, fail in the commissurotomized patient.

Cross-integration of stimuli from the hands themselves is severely impaired but not entirely eliminated – suggesting the presence of at least a weak system of basic sensory input from each hand to the ipsilateral hemisphere. Onset and persistence or absence of tactile stimulation of the left hand can be reported verbally as can also a distinction between stimuli applied to the wrist or palm, thumb or palm, and thumb or little
finger. Sharp points that yield mild pain on pressure can also be detected by the major hemisphere. More refined discrimination fail, however, as between the fingers or between curved and straight lines drawn on the palm or even between crosswise and lengthwise movements of a stylus on the palm. Considerable individual variation is to be expected in the proficiency of these weak epipilellar systems.

**INTERMODAL ASSOCIATIONS BETWEEN TACTUAL, VISUAL AND AUDITORY SPHERES**

If a picture of an object like an apple, a pencil, or an anther is flashed to the left half of the visual field, the commissurotomed subject can retrieve by touch the corresponding item from among an array of test objects out of sight. Unlike a normal person, however, the commissurotomed subject is able to do this only with the left hand when the visual cue is flashed to the right hemisphere, and it can be done only by the right hand when the visual input is in the left half-field (see Fig. 3). Conversely, if the object is first presented tactualy to the left hand, the visual picture of the object is then identifiable only when it is seen in the left half visual field and vice versa. In the normal person, of course, visual identification under these conditions goes readily in either field.

The foregoing is consistent with the conclusion, suggested by a wide variety of tests, that manual stereognosis for the left hand and visual perception of things in the left half of the visual field are both processed in the right hemisphere only. All such tests must be conducted with careful exclusion of secondary stimuli that are not confined to the intended manual and visual sensory fields. Objects that give off distinctive auditory cues like the jingle of a key case, the click or ring of a metal object, the rustle of a ball of tissue paper, etc., can subsequently be found and retrieved by blind palpation. This can be done either by hand indicating bilateral recognition and retention of the auditory percept by both hemispheres.

In summary, tasks that are dependent upon intermodal associations are possible only when the sensory and related information is all presented to the same hemisphere. The integrations between oppositely processed visual and somesthetic inputs that are easily confused with the commissurotomy intact are no longer possible.

**SPEECH AND WRITING**

Under ordinary conditions these patients get the impression of being able to conjugate in two, write at a normal level. As already explained, however, the right-handed commissurotomed patient is generally unable to express in speech or writing things seen in the left half of the visual field or felt with the left hand. By literal verbal expression is essentially meant a rule for things perceived through the right half visual field and the right hand.

These and related observations support the conclusion that speech and writing in these fields are organized almost exclusively in the major left hemisphere, and that lesions of commissures thus leaves the minor hemisphere speechless and agraphic. This conclusion may not be extended to intermodal performances and the general rule that speech and writing are possible for the comissurotomed experience of the major hemisphere only. Speech in the minor hemisphere seems to be almost totally lacking at tests applied to date. However, the ability of the minor hemisphere to sing or to utter simple, familiar, or exclamatory words (Smith 1966), to manage a little childlike writing in some cases cannot be excluded and remains to be explored.

**CALCULATION**

A year after surgery these patients were carrying out mathematical transformations verbally in writing, in testing sessions, in marketing, and in school work with a proficiency approximating the preoperative level. Difficulties in calculation are the rule in the first months after surgery. These difficulties may depend in part on diachisis after effects as well as other factors including impairments in short-term memory and incomplete scanning of the visual field all of which subsides in time. More exacting measures of the upper level of attainment are yet to be made.

Tests for mathematical performance in the minor hemisphere with nonverbal readout and with the sensory input restricted to the left visual field or the left hand, indicate, by contrast, that the capacity for calculation on the minor side is almost negligible. By manipulating digits or dowel sticks, watching spots of light flashed to the left field and pointing with the left hand, these patients may succeed in matching numbers or in adding one to numbers below ten but they fail when required to add or subtract two or higher numbers and they fall also in the simplest tasks in multiplication and division.

We have inferred accordingly that calculation in this hemisphere, along with speech and writing, is based on functions associated with the right half-field and the stereognostic functions of the right hand and all the associative and integrative activities dependent upon the forgoing are organized predominantly in the major hemisphere. Further it would seem to be these activities of the major hemisphere that set nearly all the upper limits of behavior after commissurotomy and that are mainly responsible for the impression of near normality in ordinary behavior.

**LANGUAGE COMPREHENSION IN THE MINOR HEMISPHERE**

Symptoms seen in the first patient in this series were in conformity with the view that the minor hemisphere disconnected from the language centers of the major hemisphere is rendered ‘word-blind’, ‘word-deaf’, and tactually alexic (Geschwinder 1957). This is not true of our latest cases, however, in whom comprehension of both spoken and written words has been shown, although this comprehension is not demonstrable by verbal response.

Auditory comprehension of language was indicated by the ability of the subjects to retrieve with the left hand a particular object named aloud by the examiner and located out of sight among a collection of test objects. In such tests words like the following appear to be understood in the minor hemisphere: pyramid, cylinder, tack, coin, place, fork, flashlight, bulb, screwdriver, round, square, scissors, etc. This performance was frequently successful when the test object was not directly named but only indirectly described with definitions like: ‘used to light fires with’ for a match; ‘a measuring instrument’ for ruler; or ‘liquid container’ for a glass. Because tactile recognition with this left hand was shown to be a function of the minor hemisphere, it would appear that the names and descriptions of the test objects, and to some extent the verbal instructions, must have been heard and understood by this same hemisphere.

Conversely, if an object was presented to the left visual field or the left hand, the subject could subsequently signal the name of the object when it was read aloud among a series of other names. The minor hemisphere in such tests seemed to have at least a moderate vocabulary. In these tests, however, the major hemi-
sphere also bears and comprehends the auditory material, and might therefore be suspected of aiding the minor hemisphere with feedback effects, subcortical sets, or other facilitative mechanisms.

Comprehension of written words in the minor hemisphere was demonstrated by similar procedures. After a printed word had been flashed to the left half visual field, the commissurotomized subjects were able to retrieve the corresponding item from among an array of objects by blind palpation with the left hand (Fig. 4). Conversely, after a given test object had first been recognized with the left hand, the patient could look at a list of printed names or a series of names flashed successively to the left half-field and signal by pointing to the correct name of the test object. Control by the major hemisphere in these latter tests could be excluded because incorrect verbal descriptions given immediately after a correct response by the left hand showed that it was only the minor hemisphere that knew the answer.

The discrepancy between these findings and the accounts of 'word-blindness,' and 'word-deafness' in the separated minor hemisphere remains to be accounted for. In part the discrepancy seems to stem from a failure in earlier studies to use nonverbal readout in testing for comprehension. Perhaps our subjects with early brain injury have a greater than normal bilaterization of the ability to comprehend words. Or it may be also that the disconnected minor hemisphere is capable of functioning at a higher level with the opposite hemisphere intact than where it must function in the presence of lesions on the opposite side. However, after surgical removal of the dominant hemisphere in an adult, language comprehension has been found to be far less impaired than expression (Smith 1966). It is further possible that in the presence of an aphasicogenic lesion in the left hemisphere, language comprehension by the minor hemisphere may be better in the absence of commissural influences. Only further observations can determine to what extent the picture described above represents a typical condition.

Tests involving comprehension and response to printed commands, in which the subject is instructed to mimic or carry out actions, indicate a much lower level of performance in the minor hemisphere. When very subtle movements, as 'smile, nod, frown, blow, point, wave, etc. were flashed to the left half-field, the patients were unable either to comprehend the act, but did so readily from the right half. Lack of comprehension for the left hand would seem to be the limiting factor in view of the subjects' inability even to point correctly to matching pen and ink sketches depicting test words. The patients, however, could carry out the actions correctly when the test word was flashed simultaneously with the word 'point.'

Right half-field and were able to converse, carry out verbal commands, and write on a level not noticeably different from before surgery. However, tests for exact measurement of more subjective and postoperative differences have yet to be carried out. The specific tests applied thus far have been aimed mainly at the minor side have not tested the capacities of the major hemisphere.

Fig. 4. Names of objects flashed to left half field, may be read and understood but not space-named. Subject can retrieve the named object by touch with the left hand, but cannot afterwards name the left hand or write with the right hand.
formed by L.B. with finger and wrist movement along with the forearm fixed.

Crossed motor control is measured by flashing to right and left visual field outlined sketches of the hands and fingers in different postures (Fig. 5). The subject then mimics these with the hand on the same or opposite side. The responses break down in the commissurotomized patient when the hand response is on the side opposite the visual input. Again, simple postures, such as the closed fist or the open hand or the extended thumb can be achieved under these conditions by some patients, but more differentiated poses that are readily copied on the same side fail when the contralateral hand is employed. The deficit was especially marked when the nondominant right hemisphere attempted to control the right hand. Using this combination, the patients were usually unable even to make a fist or to merely spread out the fingers and hand as a whole. Whether the occasional success of the left hemisphere—left hand combination reflects ipsilateral corticospinal control of the forearm musculature remains unclear. It may be that these simpler movements follow in part as a natural consequence of movement patterns initiated in Akselis series (Akselis 1944). The present patients were fairly good at coordinate use of two hands, as for example in catching objects, or in judging two objects, and the use of one of Akselis’ cases could play the piano and pose hemisphere decided at the same moment by touch after complete section of the genu. In these latter activities both hands play. In other words, the right hemisphere were presumably governed through the major direct the right hand toward a particular object.

The capacity of either hemisphere, and particularly the left hemisphere, to control the ipsilateral as well as the contralateral arm accounts for many of the discrepancies between the precentral and postcentral corticospinal systems other figure is also plotted to the right hemisphere at the same time. In the latter case, the right hand seems to be only able to draw in 1962 – the ability to write and to carry out verbal commands with the subordinate left hand is not adequate. When one hand is used for both hands working together on the same task, with the other hemisphere, one hemisphere seems to be more easily disrupted by visual or verbal commands, leaving in control only the contralateral crossed systems.

It would seem reasonable to conclude from one of the foregoing that the initiation of voluntary responses was not restricted to the right hemisphere. However, the presence of speech, writing, calculation, bulk of language comprehension, and the ideation dependent on these along with the motor and ideographic representation of the dominant hand would strongly favor the left as the leading hemisphere. Except in those special unusual situations in which considerable care was taken to make leading activity in the minor hemisphere, one had the impression that the separated major hemisphere was in command most of the time. Although good ipsilateral motor control of the extremities was evident after commissurotomies, one did not return to the preoperative efficiency. It would thus appear that the callosal system in such a role in the control of hand movements that are directed to the homolateral hemisphere. The exact nature of the information transmitted across the callosum in such motor activity, as well as in its various sensory and associative functions, remains to be determined.

Masking of disconnection symptoms in ordinary behavior

Whereas specific behavioral tests indicate, as described, a high order of mental activity in each of the disconnected hemispheres, and an almost complete functional separation of gross process, remarkably little evidence of this splitting and doubling of the mental controls is apparent in general behavior. The major part of the symptoms described above are readily concealed or compensated for, when the special restrictions of the testing procedures are lacking. The visual symptoms, for example, including the presence of two separate inner visual worlds is not apparent ordinarily to either the patient or an observer. These people do not complain spontaneously about a perceptual division or incompleteness in their visual experience, nor in all probability does the right hemisphere either experience or divide visual field. One can compare the visual experience of each hemisphere to that of the hemianopic patient who, following accidental destruction of one visual cortex or even hemispherectomy, may not recognize the loss of one half of visual space until this is pointed out in formal tests. The visual defects are only conspicuous when the visual material is flashed at 1/10 sec or less to prevent scanning by rapid eye movements.

Similarly the cross-integrative impairments in manual stereognosis are not apparent unless vision is excluded and auditory cues carefully controlled. Objects to be verbally identified must be kept away from the right hand and from the head and face. In many tests the major hemisphere must be prevented from talking and thus giving away the answer to the minor hemisphere through auditory channels. Similarly the minor hemisphere must be prevented so far as possible from giving nonverbal signals of various kinds to the major hemisphere. There are many indirect ways in which an informed hemisphere can cue in the uninformed hemisphere and hence conceal the commissural defect in unrestricted behavior.
minor hemispheres still leaves much to be answered (Moon and Ainslie 1962; Zangwill 1964; Ettlinger 1965). There was no question but that in most of the postoperative tested administered, the right hemisphere has been decidedly more proficent than the left. The extent to which the comprehension of language in the disconnected minor hemisphere is a result of postoperative learning also remains a question.

The above description is to be applied with caution in other respects as well. It applies to a complete surgical division of the commissures in the presence of relatively little additional cerebral damage. Complications introduced in different types of clinical cases by partial, sequent, or progressive lesions of the commissures and also by different patterns of associated cerebral damage, when added to individual differences in asymmetry of both structure and function, along with other variables introduced by training, by age, naiveté, intelligence, and related factors add up to a variety of possible manifestations of symptoms in the clinic that becomes truly formidable in their complexity and diagnostic complications. In any practical application of the foregoing, allowances should be made accordingly and also for the great plasticity of the neocortical systems in general.

Addendum

Since the above was written, the testing program has been continued with studies still in progress on the same patients and also on 4 additional new patients of Dr. Vogel, all with the same surgery. The more recent findings conform in the main the general syndrome as described above and extend its manifestations into efficacy and auxiliary modalities. The capacity for calculation in the minor hemisphere now appears to have been underestimated in the above, and some of the more elementary (mathematic) attributes of vision as well as of somesthesia have since been found to transfer across the midline. Otherwise the more recent developments are largely in the nature of individualized qualifications and natural extension of the basic syndrome as described. Some of these later details are included in subsequent publications (Sperry 1967a,b, 1968a,b; Sperry and Sperling 1968a, b; Sperry 1968b; Mitter et al. 1968). These more extended observations reveal impressively wide and range of individual variations for so small a patient series. Since these variations occur in both directions, i.e., toward greater and also toward lesser severity in different instances, the above account continues to stand as a reasonable average for the syndrome. At the same time the degree of individualization as such would seem to reflect a higher degree of functional plasticity in the commissure and related systems involved, particularly during developmental stages. Recent application of the above battery of tests to a patient with a symmetrical agnosia and apraxia of the corpus callosum disclosed almost none of the callosal symptoms previously noted by surgery in the adult (Saul and Sperry 1966). This patient, a college girl with a verbal IQ of 111 and with an average scholastic record, performed all the cross-integrative tasks prescribed above at an essentially normal level.

In other kinds of performances, however, congenital absence of the corpus callosum, this 'asymptomatic' patient appears to have a definite handicap. She is weak in arithmetic, especially geometry. Although her scores appear normal in verbal reasoning tasks, they are very low in non-verbal reasoning. In general, the abilities of the callosal functions that are not incorporated into the callosal pathways are very low. Sensitivity to impairment is found in those activities in which the specialized non-verbal and spatial faculties of the minor hemisphere were normally reinforcing, complement and enhance the verbal and visuospatial performances of the major hemisphere. With verbal functions clearly superior in at least one (maybe both) hemispheres the non-verbal, minor hemisphere faculty remains either underdeveloped for having a clearly verbally-dominated hemisphere, or is not adequately integrated with the verbal hemisphere—both.

Studies in progress along with many additional observations indicate that the above is true.

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