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HEMISPHERE DECONNECTION AND UNITY IN CONSCIOUS AWARENESS[1]

R. W. SPERRY

California Institute of Technology

THE following article is a result of studies my colleagues and I have been conducting with some neurosurgical patients of Philip J. Vogel of Los Angeles. These patients were all advanced epileptics in whom an extensive midline section of the cerebral commissures had been carried out in an effort to contain severe epileptic convulsions not controlled by medication. In all these people the surgical sections included division of the corpus callosum in its entirety, plus division also of the smaller anterior and hippocampal commissures, plus in some instances the massa intermedia. So far as I know, this is the most radical disconnection of the cerebral hemispheres attempted thus far in human surgery. The full array of sections was carried out in a single operation.

No major collapse of mentality or personality was anticipated as a result of this extreme surgery: earlier clinical observations on surgical section of the corpus callosum in man, as well as the results from dozens of monkeys on which I had carried out this exact same surgery, suggested that the functional deficits might very likely be less damaging than some of the more common forms of cerebral surgery, such as frontal lobotomy, or even some of the unilateral lobotomies performed more routinely for epilepsy.

The first patient on whom this surgery was tried had been having seizures for more than 10 years with generalized convulsions that continued to worsen despite treatment that had included a sojourn in Bethesda at the National Institutes of Health. At the time of the surgery, he had been averaging two major attacks per week, each of which left him debilitated for another day or so. Episodes of *status epilepticus* (recurring seizures that fail to stop and represent a medical emergency with a fairly high mortality risk) had also begun to occur at 2- to 3-month intervals. Since leaving the hospital following his surgery over 5½ years ago, this man has not had, according to last reports, a single generalized convulsion. It has further been possible to reduce the level of medication and to obtain an overall improvement in his behavior and well being (see Bogen & Vogel, 1962).

The second patient, a housewife and mother in her 30s, also has been seizure-free since recovering from her surgery, which was more than 4 years ago (Bogen, Fisher, & Vogel, 1965). Bogen related that even the EEG has regained a normal pattern in this patient. The excellent outcome in the initial, apparently hopeless, last-resort cases led to further application of the surgery to some nine more individuals to date, the majority of whom are too recent for therapeutic evaluation. Although the alleviation of the epilepsy has not held up 100% throughout the series (two patients are still having seizures, although their convulsions are much reduced in severity and frequency and tend to be confined to one side), the results on the whole continue to be predominantly beneficial, and the overall outlook at this time remains promising for selected severe cases.

The therapeutic success, however, and all other medical aspects are matters for our medical colleagues, Philip J. Vogel and Joseph E. Bogen. Our own work has been confined entirely to an examination of the functional outcome, that is, the behavioral, neurological, and psychological effects of this surgical disruption of all direct cross-talk between the hemispheres. Initially we were concerned as to whether we would be able to find in these patients any of the numerous symptoms of hemisphere deconnection that had been demonstrated in the so-called "split-brain" animal studies of the 1950s (Myers, 1961; Sperry, 1967a, 1967b). The outcome in man remained an open question in

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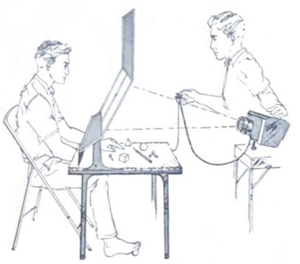

FIG. 1. Apparatus for studying lateralization of visual, tactual, lingual, and associated functions in the surgically separated hemispheres.

view of the historic Akelaitis (1944) studies that had set the prevailing doctrine of the 1940s and 1950s. This doctrine maintained that no important functional symptoms are found in man following even complete surgical section of the corpus callosum and anterior commissure, provided that other brain damage is excluded.

These earlier observations on the absence of behavioral symptoms in man have been confirmed in a general way to the extent that it remains fair to say today that the most remarkable effect of sectioning the neocortical commissures is the apparent lack of effect so far as ordinary behavior is concerned. This has been true in our animal studies throughout, and it seems now to be true for man also, with certain qualifications that we will come to later. At the same time, however—and this is in contradiction to the earlier doctrine set by the Akelaitis studies—we know today that with appropriate tests one can indeed demonstrate a large number of behavioral symptoms that correlate directly with the loss of the neocortical commissures in man as well as in animals (Gazzaniga, 1967; Sperry, 1967a, 1967b; Sperry, Gazzaniga, & Bogen, 1968). Taken collectively, these symptoms may be referred to as the syndrome of the neocortical commissures or the syndrome of the forebrain commissures or, less specifically, as the syndrome of hemisphere deconnection.

One of the more general and also more interesting and striking features of this syndrome may be summarized as an apparent doubling in most of the realms of conscious awareness. Instead of the normally unified single stream of consciousness, these patients behave in many ways as if they have two independent streams of conscious awareness, one in each hemisphere, each of which is cut off from and out of contact with the mental experiences of the other. In other words, each hemisphere seems to have its own separate and private sensations; its own perceptions; its own concepts; and its own impulses to act, with related volitional, cognitive, and learning experiences. Following the surgery, each hemisphere also has thereafter its own separate chain of memories that are rendered inaccessible to the recall processes of the other.

This presence of two minds in one body, as it were, is manifested in a large number and variety of test responses which, for the present purposes, I will try to review very briefly and in a somewhat streamlined and simplified form. First, however, let me take time to emphasize that the work reported here has been very much a team project. The surgery was performed by Vogel at the White Memorial Medical Center in Los Angeles. He has been assisted in the surgery and in the medical treatment throughout by Joseph Bogen. Bogen has also been collaborating in our behavioral testing program, along with a number of graduate students and postdoctoral fellows, among whom M. S. Gazzaniga, in particular, worked closely with us during the first several years and managed much of the testing during that period. The patients and their families have been most cooperative, and the whole project gets its primary funding from the National Institute of Mental Health.

Most of the main symptoms seen after hemisphere deconnection can be described for convenience with reference to a single testing setup—shown in Figure 1. Principally, it allows for the lateralized testing of the right and left halves of the visual field, separately or together, and the right and left hands and legs with vision excluded. The tests can be arranged in different combinations and in association with visual, auditory, and other input, with provisions for eliminating unwanted stimuli. In testing vision, the subject with one eye covered centers his gaze on a designated fixation point on the upright translucent screen. The visual stimuli on 35-millimeter transparencies are arranged in a standard projector equipped with a shutter and are then back-projected at $\frac{1}{10}$ of a second or less—too

fast for eye movements to get the material into the wrong half of the visual field. Figure 2 is merely a reminder that everything seen to the left of the vertical meridian through either eye is projected to the right hemisphere and vice versa. The midline division along the vertical meridian is found to be quite precise without significant gap or overlap (Sperry, 1968).

When the visual perception of these patients is tested under these conditions the results indicate that these people have not one inner visual world any longer, but rather two separate visual inner worlds, one serving the right half of the field of vision and the other the left half—each, of course, in its respective hemisphere. This doubling in the visual sphere shows up in many ways: For example, after a projected picture of an object has been identified and responded to in one half field, we find that it is recognized again only if it reappears in the same half of the field of vision. If the given visual stimulus reappears in the opposite half of the visual field, the subject responds as if he had no recollection of the previous exposure. In other words, things seen through the right half of the visual field (i.e., through the left hemisphere) are registered in mental experience and remembered quite separately from things seen in the other half of the field. Each half of the field of vision in the commissurotomized patient has its own train of visual images and memories.

This separate existence of two visual inner worlds is further illustrated in reference to speech and writing, the cortical mechanisms for which are centered in the dominant hemisphere. Visual material projected to the right half of the field—left-hemisphere system of the typical right-handed patient—can be described in speech and writing in an essentially normal manner. However, when the same visual material is projected into the left half of the field, and hence to the right hemisphere, the subject consistently insists that he did not see anything or that there was only a flash of light on the left side. The subject acts as if he were blind or agnostic for the left half of the visual field. If, however, instead of asking the subject to tell you what he saw, you instruct him to use his left hand to point to a matching picture or object presented among a collection of other pictures or objects, the subject has no trouble as a rule in pointing out consistently the very item that he has just insisted he did not see.

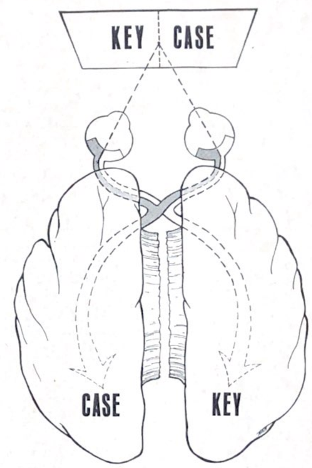

FIG. 2. Things seen to the left of a central fixation point with either eye are projected to the right hemisphere and vice-versa.

We do not think the subjects are trying to be difficult or to dupe the examiner in such tests. Everything indicates that the hemisphere that is talking to the examiner did in fact not see the left-field stimulus and truly had no experience with, nor recollection of, the given stimulus. The other, the right or nonlingual hemisphere, however, did see the projected stimulus in this situation and is able to remember and recognize the object and can demonstrate this by pointing out selectively the corresponding or matching item. This other hemisphere, like a deaf mute or like some aphasics, cannot talk about the perceived object and, worse still, cannot write about it either.

If two different figures are flashed simultaneously to the right and left visual fields, as for example a "dollar sign" on the left and a "question mark" on the right and the subject is asked to draw what he saw using the left hand out of sight, he regularly reproduces the figure seen on the left half of the field, that is, the dollar sign. If we now ask him what he has just drawn, he tells us without hesitation that the figure he drew was the question mark, or whatever appeared in the right half of the field. In other words, the one hemisphere does not know what the other hemisphere has been doing. The left and the right halves of the visual field seem to be perceived quite separately in each hemisphere with little or no cross-influence.

When words are flashed partly in the left field and partly in the right, the letters on each side of the midline are perceived and responded to separately. In the "key case" example shown in Figure 2 the subject might first reach for and select with the left hand a key from among a collection of objects indicating perception through the minor hemisphere. With the right hand he might then spell out the word "case" or he might speak the word if verbal response is in order. When asked what kind of "case" he was thinking of here, the answer coming from the left hemisphere might be something like "in *case* of fire" or "the *case* of the missing corpse" or "a *case* of beer," etc., depending upon the particular mental set of the left hemisphere at the moment. Any reference to "key case" under these conditions would be purely fortuitous, assuming that visual, auditory, and other cues have been properly controlled.

A similar separation in mental awareness is evident in tests that deal with stereognostic or other somesthetic discriminations made by the right and left hands, which are projected separately to the left and right hemispheres, respectively. Objects put in the right hand for identification by touch are readily described or named in speech or writing, whereas, if the same objects are placed in the left hand, the subject can only make wild guesses and may often seem unaware that anything at all is present. As with vision in the left field, however, good perception, comprehension, and memory can be demonstrated for these objects in the left hand when the tests are so designed that the subject can express himself through nonverbal responses. For example, if one of these objects which the subject tells you he cannot feel or does not recognize is taken from the left hand and placed in a grab bag or scrambled among a dozen other test items, the subject is then able to search out and retrieve the initial object even after a delay of several minutes is deliberately interposed. Unlike the normal subject, however, these people are obliged to retrieve such an object with the same hand with which it was initially identified. They fail at cross-retrieval. That is, they cannot recognize with one hand something identified only moments before with the other hand. Again, the second hemisphere does not know what the first hemisphere has been doing.

When the subjects are first asked to use the left hand for these stereognostic tests they commonly complain that they cannot "work with that hand," that the hand "is numb," that they "just can't feel anything or can't do anything with it," or that they "don't get the message from that hand." If the subjects perform a series of successful trials and correctly retrieve a group of objects which they previously stated they could not feel, and if this contradiction is then pointed out to them, we get comments like "Well, I was just guessing," or "Well, I must have done it unconsciously."

With other simple tests a further lack of cross-integration can be demonstrated in the sensory and motor control of the hands. In a "symmetric handpose" test the subject holds both hands out of sight symmetrically positioned and not in contact. One hand is then passively placed by the examiner into a given posture, such as a closed fist, or one, two, or more fingers extended or crossed or folded into various positions. The subject is then instructed verbally or by demonstration to form the same pose with the other hand, also excluded from vision. The normal subject does this quite accurately, but the commissurotomy patient generally fails on all but the very simplest hand postures, like the closed fist or the fully extended hand.

In a test for crossed topognosis in the hands, the subject holds both hands out of sight, forward and palm up with the fingers held apart and extended. The examiner then touches lightly a point on one of the figures or at the base of the fingers. The subject responds by touching the same target point with the tip of the thumb of the same hand. Cross-integration is tested by requiring the patient to use the opposite thumb to find the corresponding mirror point on the opposite hand. The commissurotomy patients typically perform well within either hand, but fail when they attempt to cross-locate the corresponding point on the opposite hand. A crude cross-performance with abnormally long latency may be achieved in some cases after practice, depending on the degree of ipsilateral motor control and the development of certain strategies. The latter breaks down easily under stress and is readily distinguished from the natural performance of the normal subject with intact callosum.

In a related test the target point is presented visually as a black spot on an outline drawing of the hand. The picture is flashed to the right or left half of the visual field, and the subject then attempts as above to touch the target spot with the tip of the thumb. The response again is performed on the same side with normal facility but is impaired in the commissurotomy patient when the left visual field is paired with a right-hand response and vice versa. Thus the duality of both manual stereognosis and visuognosis is further illustrated; each hemisphere perceives as a separate unit unaware of the perceptual experience of the partner.

If two objects are placed simultaneously, one in each hand, and then are removed and hidden for retrieval in a scrambled pile of test items, each hand will hunt through the pile and search out selectively its own object. In the process each hand may explore, identify, and reject the item for which the other hand is searching. It is like two separate individuals working over the collection of test items with no cooperation between them. We find the interpretation of this and of many similar performances to be less confusing if we do not try to think of the behavior of the commissurotomy patient as that of a single individual, but try to think instead in terms of the mental faculties and performance capacities of the left and the right hemispheres separately. Most of the time it appears that the major, that is, the left, hemisphere is in control. But in some tasks, particularly when these are forced in testing procedures, the minor hemisphere seems able to take over temporarily.

It is worth remembering that when you split the brain in half anatomically you do not divide in half, in quite the same sense, its functional properties. In some respects cerebral functions may be doubled as much as they are halved because of the extensive bilateral redundancy in brain organization, wherein most functions, particularly in subhuman species, are separately and rather fully organized on both sides. Consider for example the visual inner world of either of the disconnected hemispheres in these patients. Probably neither of the separated visual systems senses or perceives itself to be cut in half or even incomplete. One may compare it to the visual sphere of the hemianopic patient who, following accidental destruction of an entire visual cortex of one hemisphere, may not even notice the loss of the whole half sphere of vision until this has been pointed out to him in specific optometric tests. These commissurotomy patients continue to watch television and to read the paper and books with no complaints about peculiarities in the perceptual appearance of the visual field.

At the same time, I want to caution against any impression that these patients are better off mentally without their cerebral commissures. It is true that if you carefully select two simple tasks, each of which is easily handled by a single hemisphere, and then have the two performed simultaneously, there is a good chance of getting better than normal scores. The normal interference effects that come from trying to attend to two separate right and left tasks at the same time are largely eliminated in the commissurotomized patient. However, in most activities that are at all complex the normally unified cooperating hemispheres still appear to do better than the two disconnected hemispheres. Although it is true that the intelligence, as measured on IQ tests, is not much affected and that the personality comes through with little change, one gets the impression in working with these people that their intellect is nevertheless handicapped in ways that are probably not revealed in the ordinary tests. All the patients have marked short-term memory deficits, which are especially pronounced during the first year, and it is open to question whether this memory impairment ever clears completely. They also have orientation problems, fatigue more quickly in reading and in other tasks requiring mental concentration, and presumably have various other impairments that reduce the upper limits of performance in functions that have yet to be investigated. The patient that has shown the best recovery, a boy of 14, was able to return to public school and was doing passing work with B to D grades, except for an F in math, which he had to repeat. He was, however, a D student before the surgery, in part, it would seem, for lack of motivation. In general, our tests to date have been concerned mostly with basic cross-integrational deficits in these patients and the kind of mental capacities preserved in the subordinate hemisphere. Studied comparisons of the upper limits of performance before and after surgery are still needed.

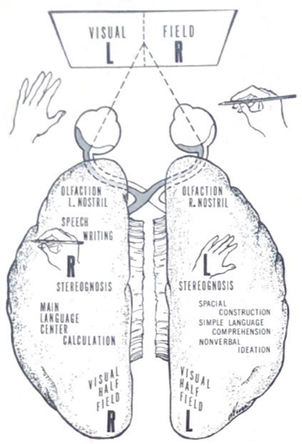

FIG. 3. Schematic outline of the functional lateralization evident in behavioral tests of patients with forebrain commissurotomy.

Much of the foregoing is summarized schematically in Figure 3. The left hemisphere in the right-handed patients is equipped with the expressive mechanisms for speech and writing and with the main centers for the comprehension and organization of language. This "major" hemisphere can communicate its experiences verbally and in an essentially normal manner. It can communicate, that is, about the visual experiences of the right half of the optic field and about the somesthetic and volitional experiences of the right hand and leg and right half of the body generally. In addition, and not indicated in the figure, the major hemisphere also communicates, of course, about all of the more general, less lateralized cerebral activity that is bilaterally represented and common to both hemispheres. On the other side we have the mute aphasic and agraphic right hemisphere, which cannot express itself verbally, but which through the use of nonverbal responses can show that it is not agnostic; that mental processes are indeed present centered around the left visual field, left hand, left leg, and left half of the body; along with the auditory, vestibular, axial somatic, and all other cerebral activities that are less lateralized and for which the mental experiences of the right and left hemispheres may be characterized as being similar but separate.

It may be noted that nearly all of the symptoms of cross-integrational impairment that I have been describing are easily hidden or compensated under the conditions or ordinary behavior. For example, the visual material has to be flashed at $\frac{1}{10}$ of a second or less to one half of the field in order to prevent compensation by eye movements. The defects in manual stereognosis are not apparent unless vision is excluded; nor is doubling in olfactory perception evident without sequential occlusion of right and left nostril and elimination of visual cues. In many tests the major hemisphere must be prevented from talking to the minor hemisphere and thus giving away the answer through auditory channels. And, similarly, the minor hemisphere must be prevented from giving nonverbal signals of various sorts to the major hemisphere. There is a great diversity of indirect strategies and response signals, implicit as well as overt, by which the informed hemisphere can be used to cue-in the uninformed hemisphere (Levy-Agresti, 1968).

Normal behavior under ordinary conditions is favored also by many other unifying factors. Some of these are very obvious, like the fact that these two separate mental spheres have only one body, so they always get dragged to the same places, meet the same people, and see and do the same things all the time and thus are bound to have a great overlap of common, almost identical, experience. Just the unity of the optic image—and even after chiasm section in animal experiments, the conjugate movements of the eyes—means that both hemispheres automatically center on, focus on, and hence probably attend to, the same items in the visual field all the time. Through sensory feedback a unifying body schema is imposed in each hemisphere with common components that similarly condition in parallel many processes of perception and motor action onto a common base. To get different activities going and different experiences and different memory chains built up in the separated hemispheres of the bisected mammalian brain, as we do in the animal work, requires a considerable amount of experimental planning and effort.

FIG. 4. In tests for ipsilateral motor control, different hand postures in outline drawing are projected one at a time to left or right visual field (see Figure 1). Subject attempts to copy the sample hand pose with the homolateral and the contralateral hand.

In motor control we have another important unifying factor, in that either hemisphere can direct the movement of both sides of the body, including to some extent the movements of the ipsilateral hand (Hamilton, 1967). Insofar as a response involves mainly the axial parts and proximal limb segments, these patients have little problem in directing overall response from sensory information restricted to either single hemisphere. Control of the distal limb segments and especially of the finer finger movements of the hand ipsilateral to the governing hemisphere, however, are borderline functions and subject to considerable variation. Impairments are most conspicuous when the subject is given a verbal command to respond with the fingers of the left hand. The absence of the callosum, which normally would connect the language processing centers in the left hemisphere to the main left-hand motor controls in the opposite hemisphere, is clearly a handicap, especially in the early months after surgery. Cursive writing with the left hand presents a similar problem. It may be accomplished in time by some patients using shoulder and elbow rather than finger movement. At best, however, writing with the left hand is not as good after as before the surgery. The problem is not in motor coordination per se, because the subject can often copy with the left hand a word already written by the examiner when the same word cannot be written to verbal command.

In a test used for more direct determination of the upper limits of this ipsilateral motor control, a simple outline sketch of a finger posture (see Figure 4) is flashed to a single hemisphere, and the subject then tries to mimic the posture with the same or the opposite hand. The sample posture can usually be copied on the same side (i.e., through the main, contralateral control system) without difficulty, but the performance does not go so easily and often breaks down completely when the subject is obliged to use the opposite hand. The closed fist and the open hand with all fingers extended seem to be the two simplest responses, in that these can most often be copied with the ipsilateral hand by the more adept patients.

The results are in accord with the thesis (Gazzaniga, Bogen, & Sperry, 1967) that the ipsilateral control systems are delicate and marginal and easily disrupted by associated cerebral damage and other complicating factors. Preservation of the ipsilateral control system in varying degree in some patients and not in others would appear to account for many of the discrepancies that exist in the literature on the symptoms of hemisphere disconnection, and also for a number of changes between the present picture and that described until 2 years ago. Those acquainted with the literature will notice that the present findings on dyspraxia come much closer to the earlier Akelaitis observations than they do to those of Liepmann or of others expounded more recently (see Geschwind, 1965).

To try to find out what goes on in that speechless agraphic minor hemisphere has always been one of the main challenges in our testing program. Does the minor hemisphere really possess a true stream of conscious awareness or is it just an agnostic automaton that is carried along in a reflex or trancelike state? What is the nature, the quality, and the level of the mental life of this isolated subordinate unknown half of the human brain—which, like the animal mind, cannot communicate its experiences? Closely tied in here are many problems that relate to lateral dominance and specialization in the human brain, to the functional roles mediated by the neocortical commissures, and to related aspects of cerebral organization.

With such in mind, I will try to review briefly some of the evidence obtained to date that pertains to the level and nature of the inner mental life of the disconnected minor hemisphere. First, it is clear that the minor hemisphere can perform intermodal or cross-modal transfer of perceptual and mnemonic information at a characteristically human level. For example, after a picture of some object, such as a cigarette, has been flashed to the minor hemisphere through the left visual field, the subject can retrieve the item pictured from a collection of objects using blind touch with the left hand, which is mediated through the right hemisphere. Unlike the normal person, however, the commissurotomy patient is obliged to use the corresponding hand (i.e., the left hand, in this case) for retrieval and fails when he is required to search out the same object with the right hand (see Figure 5). Using the right hand the subject recognizes and can call off the names of each object that he comes to if he is allowed to do so, but the right hand or its hemisphere does not know what it is looking for, and the hemisphere that can recognize the correct answer gets no feedback from the right hand. Hence, the two never get together, and the performance fails. Speech and other auditory cues must be controlled.

It also works the other way around: that is, if the subject is holding an object in the left hand he can then point out a picture of this object or the printed name of the object when these appear in a series presented visually. But again, these latter must be seen through the corresponding half of the visual field; an object identified by the left hand is not recognized when seen in the right half of the visual field. Intermodal associations of this sort have been found to work between vision, hearing and touch, and, more recently, olfaction in various combinations within either hemisphere but not across from one hemisphere to the other. This perceptual or mnemonic transfer from one sense modality to another has special theoretical interest in that it is something that is extremely difficult or impossible for the monkey brain. The right hemisphere, in other words, may be animallike in not being able to talk or write, but in performances like the foregoing and in a number of other respects it shows mental capacities that are definitely human.

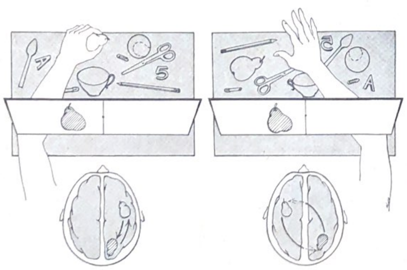

FIG. 5. Visuo-tactile associations succeed between each half of the visual field and the corresponding hand. They fail with crossed combinations in which visual and tactual stimuli are projected into opposite hemispheres.

Other responses from the minor hemisphere in this same testing situation suggest the presence of ideas and a capacity for mental association and at least some simple logic and reasoning. In the same visuo-tactual test described above, the minor hemisphere, instead of selecting objects that match exactly the pictured item, seems able also to select related items or items that "go with" the particular visual stimulus, if the subject is so instructed. For example, if we flash a picture of a wall clock to the minor side and the nearest item that can be found tactually by the left hand is a toy wrist watch, the subjects significantly select the watch. It is as if the minor hemisphere has an idea of a timepiece here and is not just matching sensory outlines. Or, if the picture of a dollar sign is flashed to the minor side, the subject searches through the list of items with the left hand and finally selects a coin such as a quarter or a 50¢ piece. If a picture of a hammer is presented, the subject may come up with a nail or a spike after checking out and rejecting all other items.

The capacity to think abstractly with symbols is further indicated in the ability of the minor hemisphere to perform simple arithmetical problems. When confronted with two numerals each less than 10, the minor hemisphere was able in four of six subjects so tested to respond with the correct sum or product up to 20 or so. The numbers were flashed to the left half of the visual field or presented as plastic block numerals to the left hand for identification. The answer was expressed by pointing to the correct number in columns of seen figures, or by left-hand signals in which the fingers were extended out of the subject's sight, or by writing the numerals with the left hand out of sight. After a correct left-hand response had been made by pointing or by writing the numeral, the major hemisphere could then report the same answer verbally, but the verbal report could not be made prior to the left-hand response. If an error was made with the left hand, the verbal report contained the same error. Two different pairs of numerals may be flashed to right and left fields simultaneously and the correct sum or products signaled separately by right and left hands. When verbal confirmation of correct left-hand signals is required under these conditions, the speaking hemisphere can only guess fortuitously, showing again that the answer must have been obtained from the minor and not from the major hemisphere. This has been demonstrated recently in a study still in progress by Biersner and the present writer. The findings correct an earlier impression (Gazzaniga & Sperry, 1967) in which we underestimated the capacity for calculation on the minor side. Normal subjects and also a subject with agenesis of the callosum (Saul & Sperry, 1968) were able to add or to multiply numerals shown one in the left and one in the right field under these conditions. The commissurotomy subjects, however, were able to perform such calculations only when both numerals appeared in the same half of the visual field.

According to a doctrine of long standing in the clincial writings on aphasia, it is believed that the minor hemisphere, when it has been disconnected by commissural or other lesions from the language centers on the opposite side, becomes then "word blind," "word deaf," and "tactually alexic." In contradiction to this, we find that the disconnected minor hemisphere in these commissurotomy patients is able to comprehend both written and spoken words to some extent, although this comprehension cannot be expressed verbally (Gazzaniga & Sperry, 1967; Sperry, 1966; Sperry & Gazzaniga, 1967). If the name of some object is flashed to the left visual field, like the word "eraser," for example, the subject is able then to search out an eraser from among a collection of objects using only touch with the left hand. If the subject is then asked what the item is after it has been selected correctly, his replies show that he does not know what he is holding in his left hand—as is the general rule for left-hand stereognosis. This means of course that the *talking* hemisphere does not know the correct answer, and we concluded accordingly that the minor hemisphere must, in this situation, have read and understood the test word.

These patients also demonstrate comprehension of language in the minor hemisphere by being able to find by blind touch with the left hand an object that has been named aloud by the examiner. For example, if asked to find a "piece of silverware," the subject may explore the array of test items and pick up a fork. If the subject is then asked what it is that he has chosen, he is just as likely in this case to reply "spoon" or "knife" as fork. Both hemispheres have heard and understood the word "silverware," but only the minor hemisphere knows what the left hand has actually found and picked up. In similar tests for comprehension of the spoken word, we find that the minor hemisphere seems able to understand even moderately advanced definitions like "shaving instrument" for razor or "dirt remover" for soap and "inserted in slot machines" for quarter.

Work in progress shows that the minor hemisphere can also sort objects into groups by touch on the basis of shape, size, and texture. In some tests the minor hemisphere is found to be superior to the major, for example, in tasks that involve drawing spatial relationships and performing block design tests. Perceptive mental performance in the minor hemisphere is also indicated in other situations in which the two hemispheres function concurrently in parallel at different tasks. It has been found, for example, that the divided hemispheres are capable of perceiving different things occupying the same position in space at the same time, and of learning mutually conflicting discrimination habits, something of which the normal brain is not capable. This was shown in the monkey work done some years ago by Trevarthen (1962) using a system of polarized light filters. It also required section of the optic chiasm, which of course is not included in the human surgery. The human patients, unlike normal subjects, are able to carry out a double voluntary reaction-time task as fast as they carry out a single task (Gazzaniga & Sperry, 1966). Each hemisphere in this situation has to perform a separate and different visual discrimination in order to push with the corresponding hand the correct one of a right and left pair of panels. Whereas interference and extra delay are seen in normal subjects with the introduction of the second task, these patients with the two hemispheres working in parallel simultaneously perform the double task as rapidly as the single task.

The minor hemisphere is also observed to demonstrate appropriate emotional reactions as, for example, when a pinup shot of a nude is interjected by surprise among a series of neutral geometric figures being flashed to the right and left fields at random. When the surprise nude appears on the left side the subject characteristically says that he or she saw nothing or just a flash of light. However, the appearance of a sneaky grin and perhaps blushing and giggling on the next couple of trials or so belies the verbal contention of the speaking hemisphere. If asked what all the grinning is about, the subject's replies indicate that the conversant hemisphere has no idea at this stage what it was that had turned him on. Apparently, only the emotional effect gets across, as if the cognitive component of the process cannot be articulated through the brainstem.

Emotion is also evident on the minor side in a current study by Gordon and Sperry (1968) involving olfaction. When odors are presented through the right nostril to the minor hemisphere the subject is unable to name the odor but can frequently tell whether it is pleasant or unpleasant. The subject may even grunt, make aversive reactions or exclamations like "phew!" to a strong unpleasant smell, but not be able to state verbally whether it is garlic, cheese, or some decayed matter. Again it appears that the affective component gets across to the speaking hemisphere, but not the more specific information. The presence of the specific information within the minor hemisphere is demonstrated by the subject's correct selection through left-hand stereognosis of corresponding objects associated with the given odor. The minor hemisphere also commonly triggers emotional reactions of displeasure in the course of ordinary testing. This is evidenced in the frowning, wincing, and negative head shaking in test situations where the minor hemisphere, knowing the correct answer but unable to speak, hears the major hemisphere making obvious verbal mistakes. The minor hemisphere seems to express genuine annoyance at the erroneous vocal responses of its better half.

Observations like the foregoing lead us to favor the view that in the minor hemisphere we deal with a second conscious entity that is characteristically human and runs along in parallel with the more dominant stream of consciousness in the major hemisphere (Sperry, 1966). The quality of mental awareness present in the minor hemisphere may be comparable perhaps to that which survives in some types of aphasic patients following losses in the motor and main language centers. There is no indication that the dominant mental system of the left hemisphere is concerned about or even aware of the presence of the minor system under most ordinary conditions except quite indirectly as, for example, through occasional responses triggered from the minor side. As one patient remarked immediately after seeing herself make a left-hand response of this kind, "Now I know it wasn't me did that!"

Let me emphasize again in closing that the foregoing represents a somewhat abbreviated and streamlined account of the syndrome of hemisphere deconnection as we understand it at the present time. The more we see of these patients and the more of these patients we see, the more we become impressed with their individual differences, and with the consequent qualifications that must be taken into account. Although the general picture has continued to hold up in the main as described, it is important to note that, with respect to many of the deconnection symptoms mentioned, striking modifications and even outright exceptions can be found among the small group of patients examined to date. Where the accumulating evidence will settle out with respect to the extreme limits of such individual variations and with respect to a possible average "type" syndrome remains to be seen.

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