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Brain Research
Some Head-Splitting Implications

R. W. Sperry

I must emphasize at the outset that language and especially speech is not my line--in more ways than one. Neither are hearing and audiology my line. The same goes for the training of aphasic, brain-damaged, and retarded children and adults as well. If you then are beginning to wonder why in the world I should have been called in to talk at this conference we now at last begin, I think, to reach some common ground, some common concern.

As I see it, it is perhaps because if I were working in these areas, I might find in the material that I do study things of interest from the language standpoint, some perhaps even with practical and theoretical implications.

And now to get down to business. What I've brought along as the excuse for this evening's social hour is a brief outline of some observations that my colleague Dr. Gazzaniga and myself have been making in the course of studies[1] that we have been running on two patients that have undergone a rather special kind of brain surgery. This surgery was performed by Drs. Philip Vogel and Joseph Bogen of the California College of Medicine at the White Memorial Hospital in Los Angeles, about two and three years ago, respectively, in an effort to alleviate severe epileptic seizures that had become resistant to medication.

The brain surgery consisted of cutting the cross connections between the right and left sides of the brain. Essentially it resulted in a disconnection of the cerebral hemispheres, a bisection of the brain down the midline into right and left halves. More specifically, for those familiar with anatomical terms, the surgery involved section of the corpus callosum, the anterior commissure, the hippocampal commissure, and the massa intermedia. So far as we know, these are the first two people in the world ever to have had so complete a disconnection of the right and left hemispheres of the brain.

It was hoped in advance that this surgery might help to prevent the spread of seizures from one to the other hemisphere, and that it might help to preserve consciousness in one hemisphere at least during the early stages of an attack, enabling the patient to take precautionary measures. It was hoped that the disconnection might reduce the severity of attack, particularly in the generalized phase, by the removal of what must be a powerful avenue for mutual reinforcement of the seizure between right and left sides. That this surgery should also have reduced the incidence of the seizures almost to zero, as it has done in both cases, came as something of a surprise and a bonus. Neither of these persons has had a major convulsion since leaving the hospital and this was some two and three years ago. The reason for this therapeutic success, and how long it will hold up, remains uncertain. Some additional cases operated upon more recently show less favorable outcomes although the therapeutic picture in these latter is still uncertain.

One could predict from some ten years of animal study that this disconnection of the hemispheres would probably not materially affect the generalized behavior of these persons under ordinary conditions; that it would not affect seriously either the person's temperament or personality, and further, that it would not produce any marked disruption of general intellect. All this has proven to be generally true. Remember, in this connection, that this kind of surgery leaves intact all the main control centers of the brain, and all their interconnections within each hemisphere. The control centers of the brain tend to be double, with each side a mirror image of the other. All that has been cut in this surgery are the cross connections between right and left hemispheres, leaving the essential controls intact.

One might also predict from the animal studies that this surgery would leave these persons with essentially two separate half-brains, each with a unified mind of its own. From the testing of cats and monkeys similarly operated, it has long been clear that each hemisphere senses, perceives, comprehends, learns, remembers, and carries out volitional acts pretty much on its own, independent of the other hemisphere. Similarly, in these patients, our functional tests have seemed to indicate that the surgery has left these people with two separately conscious mental spheres. The conscious experience of the one brain half seems to be entirely outside the realm of awareness of the other, almost as much as is the case with separate brains in separate skulls—with a few minor qualifications that I'll mention later on.

For example, it could be shown in testing the vision of these persons that neither hemisphere has any knowledge at all of what is seen by the other hemisphere. Recall in this connection that the right half of the visual field is represented in the left hemisphere, and vice versa. In testing vision we have the subject fixate on a central point in the middle of a viewing screen, or on a point between two viewing screens, and we then flash visual stimuli at 1/10th to 1/50th of a second into the left and right halves of the visual field—so fast that the persons are unable to sneak the test material across into the opposite hemisphere by the use of eye or head movements. When we thus flash visual material by this tachistoscopic or quick-flash method into the right or left halves of the visual field, it is very clear that the subject responds in a practically normal manner to all material presented to the right half-field. The subjects are able to read and to interpret all visual material in a practically normal manner. Remember that we are dealing here with the left and dominant hemisphere. The sensory input is into the dominant hemisphere containing the speech centers, and the output is also via the speech and motor centers of that same hemisphere which also control the right hand.

When the same kind of material is flashed to the left half of the visual field (normally controlled by the right hemisphere) we find the subjects are unable to report anything at all. They simply say that they see "nothing" or at most "a white flash." Despite their inability to communicate in spoken language any information about what has been presented to the left half-field, it is easy to show by the use of non-verbal, non-linguistic responses, that these subjects nevertheless do perceive and comprehend much of the material that enters the left half-field. If, instead of verbal responses, we have the person point with the left hand at different parts of the stimulus, or pick up matching material on sample cards, or retrieve objects corresponding to those that were flashed from an array of different objects placed on a table in front of him, it is possible to show under these conditions that the minor hemisphere does indeed see and comprehend the greater part of the visual material that is flashed to that hemisphere.

In the course of making this kind of test, we've been unable to get any evidence that visual perception in one half-field is influenced in any way by what is seen in the other half-field—even under the very simplest conditions. For example, if we flash the colors red and green on a random schedule into the left and right half-fields simultaneously, the subject is unable to say whether the colors are the same or different. Or, if we present simple lines or bars running across the screen from left to right, the subject is unable to say whether the lines are straight or bent at the midline.

If we expose simultaneously two different kinds of stimulus patterns, as for example a square in the left half-field, and a circle in the right half-field, and we then ask the subject what he saw, he characteristically will report a circle and only that. Meanwhile, if we ask him to pick up with the left hand the proper card with the corresponding stimulus he will unhesitatingly pick up the square with the left hand, thus disregarding his expressed opinions of the other half-brain.

Much the same kind of result is obtained in testing the sensory and motor functions of the hand. The patients have no trouble at all in working with the right hand connected to the speech hemisphere. (Remember again that the right hand and the right half of the visual field and the speech center are all in the same half of the brain—the dominant or major hemisphere.) It's an entirely different story, however, when it comes to using the left hand with the eyes blindfolded. For example, when familiar objects like a pencil, a comb, a cigarette, keys, glasses and the like are placed in the left hand, the person is completely unable to name or to describe these objects and can do no more than guess. If we avoid linquistic responses, however, and depend on simple, manual reactions of the left hand, it's possible again to show that perception and comprehension are present in the minor hemisphere. This is evident in the way the left hand handles and manipulates the test objects. It can demonstrate how they are supposed to be used. Or if the object is taken away and put inside a grab-bag among many other objects, the patient is quite able to go in and retrieve the correct object. Or, using the left hand, these people can match samples of objects previously presented to the left hand, or they can point to corresponding objects using vision after the objects have been felt and identified by the left hand. Note here that we have a cross-modal reaction from tactile sense in the hand to vision. This and similar findings indicate that the minor hemisphere has something like an *idea* of what the object is.

In simple tests for localization of points on the body surface we find that within each hand the localization is excellent, but that it is impossible for the person to point with one hand to points touched on the other hand. Or, if one taps lightly from one to four or five times on the hand or the leg, the subject can count and tap back the correct number of times with the same hand or the homolateral leg. But again it is quite impossible for him to go from the hand or foot on one side to the opposite side. In brief, the sensations, perceptions and feelings that come to the one hemisphere from one hand are inaccessible to the conscious awareness of the other hemisphere.

In testing the motor reactions from the two hands, it again is clear that each hand tends to be controlled mainly and most easily from its own hemisphere. Particularly in the early months after surgery there is special difficulty in attempting to use the left hand in voluntary movements. It would appear that under normal conditions the control of the left hand in voluntary movement is highly dependent on the callosal cross-connections from the speech centers in the left hemisphere to the motor centers for the left hand in the right hemisphere, indicating a kind of asymetry in voluntary control, wherein the dominant hemisphere uses the corpus calloum to govern the left hand. The ability of each hemisphere to govern the homolateral or unfavored hand tends to improve gradually with time, though at this date there is still some stammering-like uncertainty seen in the control of the left hand by the dominant hemisphere. The weakest combination here is that in which the minor hemisphere attempts to control the right hand, as for example when it atempts to direct the right hand to something in the left half of the visual field.

Dissociated or antagonistic movements between right and left hand are reported by both patients to be something of a nuisance, considerably worse in Case I than in Case II. For example, in attempting to dress, we were told that in the course of pulling on his trousers the left hand may work along with the right, but it also may at any point begin to pull the trousers downward while the right is pulling them upward. Or, in tying the belt of his robe, the two hands may work together very nicely, but after the knot is all tied and the person starts off to something else, the left hand may meanwhile continue to work at the knot and soon has it all untied, wherupon the right hand has to supervene and retie the knot all over again. Or, in carrying things around, the two hands may work together, but sometimes the left hand will throw things into the waste basket and then the right hand will have to pick them up again. As I say, these antagonistic and dissociated movements were much more severe in Case I and presumably were exaggerated by the considerable brain damage sustained long before surgery. The lack of coordination between the hands was also somewhat of a bother in Case II, however, as, for example, in ironing or cooking when the hands were being used together simultaneously and it was not possible to keep an eye on both of them constantly. There has been a gradual improvement in motor control, however, so that each hemisphere, and especially the major hemisphere is able to control increasingly the ipsilateral or unfavored hand. This has progressed in Case II to the point where this person can even do some writing with the left hand. It's not a matter of the minor hemisphere learning to write here, but rather a matter of the major hemisphere learning to control the minor hand. This can be shown by putting visual or other material into the one hemisphere to be read out by writing. Very commonly if we want to favor attention to one or the other hemisphere in the course of testing we force the person to work with the corresponding hand, putting the other hand behind his back, or sitting on it, etc.

Further evidence of the functional separation of the two hemispheres is seen in measurements on the speed of visual reaction time. In general these patients are somewhat slower than normal from the beginning, even before surgery, partly perhaps because of the fairly heavy medication and sedation. If one sets up a double reaction time with one set of stimuli in the right half-field to be responded to with the right hand, and another set of stimuli in the left half-field to be responded to with the left hand simultaneously, it is clear that for normal subjects the introduction of the second discrimination for the second hand markedly slows the speed of the response—one problem, of course, interfering with rapid reaction to the other. But in the split-brain subjects the two problems are performed just as fast as one problem.

The emphasis thus far has been on functional separation. We might look briefly now at the other side, i.e., at some of the unifying factors that remain and that help to maintain normal unified function in these individuals. When one tests cutaneous localization of points on the body surface, it's very clear that the points on the head and neck, in contrast to those for the hand, are represented bilaterally, i.e., both sides of the head, neck, and face are represented in both hemispheres. The trunk tends to be intermediate in this respect, showing some bilaterality in its representation. Also it is known from animal studies that conjugate movement of both eyes and bilateral movement of the head, neck and trunk are obtained from stimulation of either hemisphere. This bilaterality in the motor and sensory representation of the head, neck, and axial structures is one unifying element. Also, of course, the eyes look at much the same scene all day long, and with scanning movements get the same material into both hemispheres. Similarly with the hands it is very simple for the right hand to reach across under ordinary conditions and scan something that the left hand doesn't at first recognize. These and other unifying factors make the functional deficits that we've been talking about go pretty much unnoticed under ordinary circumstances. To demonstrate them requires special testing conditions such as the quick-flash presentation of visual material, blindfolding the eyes, keeping the hands from crossing, avoidance of auditory cues, and so on. Case II is a housewife and mother who does the family cooking, runs the home, does the marketing, goes out to drive-in theaters for up to three hours at a time, and does all of this without any complaint about a lack of unity in the perceptual or mental sphere. The family reports that she is still a little disoriented spatially when it comes to turning correctly to right or left, for example to get back to her car or to find her way in unfamiliar surroundings.

We turn now to another more specific aspect of speech and language. From what we've been over so far it is clear that this kind of surgery produces "mental duplicity," but no "double-talk." One hemisphere, the left or dominant, having good practically normal speech and also writing, and the other, the right or minor hemisphere being left speechless and unable to write. One now wonders whether the hemisphere that cannot communicate is therefore totally lacking in language capacity including comprehension. We've been talking so far almost entirely about motor expression. When we apply tests so designed that comprehension alone is required, it can be shown that comprehension is indeed present in the minor hemisphere even though motor expression is absent. Case II is a better example of this because of the lack of any history of prior brain damage. If one flashes visual material to the left half-field, including words like apple, cup, fork, into the minor hemisphere, this subject can retrieve or point to the same or to a matching object. Such tests that require only a manual pointing or picking up of a card with the left hand, show that the minor hemisphere can read simple printed words and understand what they mean. Also, upon verbal instruction to find such test objects placed out of sight, the subject can comprehend sufficiently with the minor hemisphere to pick out by palpation with the left hand the correct or corresponding object. Or, the minor hemisphere can do the reverse: that is, holding an object in the left hand while the experimenter reads off a series of names, this subject can raise the hand to signal the correct name for the given object. Recall here that information from the left hand is relayed only to the minor hemisphere. One can also demonstrate in the minor hemisphere a sense of number, and a little calculation at a very low level. This subject can pick out by palpation with the left hand and with vision excluded, a block with two, four, three, or five pegs on it upon command, indicating a comprehension of number at this low level. She can also apparently do some very simple adding in the range of 1 to 10 but not multiplying or subtracting, and that seems to be about it.

The upper limits of calculation, comprehension, thought, reason, and other mental capacities in the minor hemisphere have still to be determined So far as language goes, at least, the upper limits seem to be set at a rather low level as our studies now stand. Possibly the language capacity of the minor hemisphere represents that of about the five year old stage, the stage, that is, when speech begins to become irreversibly lateralized into a dominant hemisphere. Up until that age, you remember, language can be taken over by either hemisphere in the case of brain damage on one side. It begins to look now, however, as if we have been underestimating the minor hemisphere.

In all tests I've mentioned thus far the major hemisphere has been superior to the minor. There are a few tasks, however, at which the minor hemisphere is superior to the major, as for example, in drawing perspective and spatial relationships, and in block design tests. In the performance of the block design test it is also possible to distinguish between the comprehension, recognition or perceptual aspects of the performance and its motor expression. It is clear that the weaker, in this case the major, hemisphere recognizes the errors that it makes, is unhappy about them and tries to correct them but simply is unable to control the hands in order to get them to do the proper thing. It may be that in the evaluation of cerebral dominance and lateral specialization in general, motor expression tends to lead the way with lateralization of comprehension coming later.

These notes are based upon an informal talk given by Dr. Sperry at the CSHA Southern Section Conference in Palm Spring, May, 1965.

REFERENCES

[1]*The studies referred to have been a team project. The surgical treatment was proposed initially by Dr. Joseph Bogen after extensive consultations. The surgery was performed by Dr. Philip Vogel assisted by Dr. Bogen and other staff members of the White Memorial Medical Center in Los Angeles. Most of the functional testing has been carried out by Dr. Michael Gazzaniga in our laboratory at Caltech with the writer collaborating on an advisory basis. The original more detailed publications on which the present account is based may be found as follows:*

[2]GAZZANIGA, BOGEN, and SPERRY; *Proc. Nat. Acad. Sci.,* 1962, 48, Part 2, 1765-1769; *Neuropsychologia,* 1963, 1, 209-215; *Brain,* in press; see also *Scientific American* 1963; SPERRY, R. W.; *Scientific American* 58:42-52 (1964); *Science* 133:1749-57.