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Brain Bisection and Mechanisms of Consciousness

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During the past decade we have been engaged in studies in which the brain is surgically divided down the middle into right and left halves. The behavioral performances of cats and monkeys following brain bisection have led to the conclusion that each of the surgically separated hemispheres must sense, perceive, learn, and remember quite independently of the other hemisphere [Sperry, 1961a, 1961b; 1964a, 1964b].

The past two years these studies have included two human patients in whom similar disconnection of the hemispheres had been performed in an effort to help control severe epileptic seizures [Bogen and Vogel, 1962; Gazzaniga, Bogen, and Sperry, 1962, 1963, 1965]. The findings most relevant and interesting to the subject of the conference are best illustrated in the latter subjects and I will therefore focus on the human material. The surgery in these patients included complete section of the corpus callosum and the anterior and hippocampal commissures plus the massa intermedia in one case. In the other case the massa intermedia was judged to be absent in the course of the operation [Bogen and Vogel, 1962].

It was hoped that this surgical disconnection of the hemispheres as indicated above might help prevent the spread of epileptic seizures from one to the other hemisphere in these patients, that it might help to retain consciousness in one hemisphere during the onset of the attack at least, and that it might further reduce the severity of the attack by

eliminating a powerful avenue for mutual bilateral reinforcement, particularly in the generalized phase. Postsurgical epileptic-like seizures in our colony of split-brain monkeys that have had the same surgery tend to be confined to one side and centered in the distal joints of the arm and leg on the one side. That the surgery would, in addition, reduce the incidence of the attacks to practically zero and permit reduction in the amount of medication, as has been the case in both patients, was something of a surprise bonus, and our fingers are still crossed on this latter point.

These studies represent a team effort: The surgical treatment was initially recommended by Joseph Bogen after extensive consultations. The surgery was performed by Philip Vogel at the White Memorial Hospital in Los Angeles. Most of the psychological testing has been administered by Michael Gazzaniga in our laboratory, with the writer collaborating and aiding in a general consultant and advisory capacity.

Everything we have seen so far indicates that the surgery has left these people with two separate minds, that is, two separate spheres of consciousness. What is experienced in the right hemisphere seems to be entirely outside the realm of awareness of the left hemisphere. This mental division has been demonstrated in regard to perception, cognition, volition, learning, and memory. One of the hemispheres, the left, dominant or major hemisphere, has speech and is normally talkative and conversant. The other, the minor hemisphere, however, is mute or dumb, being able to express itself only through nonverbal reactions. (Hence: "mental duplicity" from this surgery but no "double talk.")

Fortunately, from the patient's standpoint, the functional separation of the two hemispheres is counteracted by a large number of unifying factors that tend to keep the disconnected hemispheres doing pretty much the same thing from one part of the day to the next. Ordinarily there would appear to be a large common denominator of similar activity going in each most of the time. When we deliberately induce different activities in the right and left hemispheres by means of various testing procedures, however, it then becomes evident that each hemisphere is oblivious to the cognitive experience of the other.

This is illustrated in many ways. For example: the subject may be blindfolded and some familiar object such as a pencil, a cigarette, a comb, or a coin placed in the left hand. Under these conditions, the mute hemisphere connected to the left hand feeling the object perceives and appears to know quite well what the object is. Though it cannot express this knowledge in speech or in writing, it can manipulate the object correctly, it can demonstrate how the object is supposed to be used, and it can remember the object and go out and retrieve it with the same hand from among an array of other objects either by touch

or by sight. While all this is going on, the other hemisphere meanwhile has no conception of what the object is and, if asked, says so. If pressed for an answer, the speech hemisphere can only resort to pure guesswork. This remains the case just so long as the blindfold is kept in place and all other avenues of sensory input from the object to the talking hemisphere are blocked. But let the right hand cross over and touch the test object in the left hand; or let the object itself touch the face or head as in demonstrating the use of a comb, a cigarette, or glasses; or let the object make some give-away sound, like the jingle of a key case, then immediately the speech hemisphere also comes across with the correct answer.

The same kind of right-left mental separation is seen in tests involving vision. Recall that the right half of the visual field, along with the right hand, is represented together in the left hemisphere, and vice versa. Visual stimuli such as pictures, words, numbers, and geometric forms flashed on a screen directly in front of the subject and to the right side of a central fixation point, so that they are projected to the dominant speech hemispheres, are all described and reported correctly with no special difficulty. On the other hand, similar material flashed to the left half of the visual field and hence into the minor hemisphere are completely lost to the talking hemisphere. Stimuli flashed to one half field seem to have no influence whatever, in tests to date, on the perception and interpretation of stimuli presented to the other half field.

The subjects fail on such simple tasks, for example, as that involved in discriminating whether red and green half fields presented together are the same or different in color where the response involves only a simple nodding or shaking of the head "yes" or "no"—in other words, with everything favoring any cross integration that might be present. The same task caused no difficulty to either hemisphere when the two colors or other stimuli were presented within the same half retinal field and hence projected to the same hemisphere.

Comparison of the directional tilt of broad straight lines running across the visual field and interrupted in the center of the screen went easily, again, when both parts of the bar fell in one field; but when the two parts fell in right and left fields separately, the subjects were unable to indicate whether the two bars were lined up straight across the midline or at an angle. When the response in this test involved manual copying of the perceived lines, the initial result was for each hand to record and draw only the part of the line within its own half of the visual field, the other half being omitted. When both hands had a pencil and worked simultaneously, both parts of the line were drawn correctly, indicating double simultaneous perception and response. With further practice, Case II has learned gradually to reproduce the lines from both

half fields with either hand. Meantime, the verbal response has remained firmly lateralized, indicating that the change reflects an improvement in the bilaterality of motor control rather than in the sensory or perceptual sphere. The dominant hemisphere, in particular, has good motor control over both hands, even to the point where the left hand, at one year after surgery, can be used again for simple writing. Testing shows this left-hand writing is controlled from the left hemisphere.

Note in passing that the observed disconnection effects, as in the foregoing examples, do not show up readily in ordinary behavior. They have to be demonstrated by flashing the visual material fast enough so that eye movements cannot be used to sneak the answers into the wrong hemisphere. In the testing of tactile perception in right and left hands, vision has to be excluded with a blindfold, auditory cues must be eliminated, and the hands must be kept from crossing, and so on. The overall condition is amazingly normal considering the state of the brain. The second patient, less handicapped by other medical complications than the first case, has been able since surgery to run her house and to do the family cooking. She also goes out to the market, watches television, and attends full three-hour shows at the drive-in theater, all without complaining about any particular splitting or doubling in her perceptual experience. Her family believes that she still does not have as much initiative as previously in her house cleaning, in which she used to be meticulous, and that her general spatial orientation is not as good as before—for example, she does not find her way back to the car at the drive-in theater as readily as she used to. In the early months after surgery there were complaints about difficulty with short-term memory. By now, some eight months later, there seems to be much improvement in this regard, though not complete recovery. Involvement of the hippocampal fornix would have to be ruled out before effects such as the latter can be ascribed to the commissurotomy per se. Lack of coordination in activities that require close cooperation between the hands was also an early complaint that has become much less bothersome as the months go by.

Functional independence of the hemispheres is more readily apparent in Case I than in Case II. In the first case, the left hand and left half visual field and left half of the cutaneous field of the torso all function together without trouble. This left side experience, however, cannot be integrated with stimuli coming in from across the midline. The same was true for the right hand, right half of the torso and right half visual field. Construction of spatial relations and perspective in drawing went better with the left side and the minor hemisphere, whereas language functions were decidedly better on the right side and in the dominant left hemisphere. In the second case, the functional

right-left separation is no longer so clear-cut and simple, although it was very similar during the first months after surgery while trophic shock, from the commissural sections, was still strong. Voluntary motor control of the left arm and hand was much more severely affected than that of the right in the early weeks after surgery. By the seventh month, either hand was being controlled from either hemisphere, which made it much more difficult to determine which hemisphere was involved in a given activity.

One finds plenty of evidence, especially in Case II, that the minor, dumb, or mute hemisphere really does perceive and comprehend, even though it cannot express verbally what it sees and thinks. It can point out with the left hand a matching picture from among many others that have been flashed to the left field, or it can point to a corresponding object a picture of which had been flashed in the left field screen. It can also pick out the correct written name of an object it has seen flashed on the screen, or even vice versa, that is, it can read a name and retrieve the designated object. In other words, the dumb right hemisphere in the second patient is not entirely stupid or illiterate; it reads a word like *cup, fork,* or *apple* flashed to the left field and then picks out the corresponding object with the left hand. While the left hand and its hemisphere are thus performing correctly, however, the opposite hemisphere, again, has no idea at all which object or which picture or which name is the correct one, and makes this clear through its verbal as well as other responses. In such tests you frequently have to convince the talking hemisphere to keep quiet and to let the left hand go ahead on its own, in which case it will usually pick out the correct answer.

These minor differences of opinion between the right and the left hemisphere are seen rather commonly in testing situations. For example, the left hand is allowed to feel and to manipulate, say, a toothbrush under the table or out of sight behind a screen. Then a series of five to ten cards is laid out with names on them like *ring, key, fork,* and so on. When asked what the test object was, the subject may tell you that the toothbrush in the left hand is a *ring* or some other irrelevant object that happens to come to mind. However, when instructed to point with the left hand, the speechless hemisphere deliberately ignores the erroneous verbal opinions of its better half and goes ahead independently to point out the correct answer, in this case the card bearing the word *toothbrush.*

As far as we can see, about the only avenue remaining for direct communication between the two cognitive entities, *mind-right* and *mind-left,* is that of extrasensory perception. If any two minds should be able to tune in on each other, one might expect these two to be able to do

so. Thus far, however, there is no evidence that such effects have any appreciable influence in the test performances.

The stimulation of a point on the face in these people with separated hemispheres is doubly perceived, the stimulus being projected bilaterally into each hemisphere. In this situation there are presumably two separate systems perceiving, that is, conscious of the same thing, in the same way that two separate brains in two separate people look at and perceive the same event straight in front of them. In a normal person, also, it would appear that there must be much the same sort of double sensing by the left and also by the right hemisphere—at least there is no way to rule it out. Normally each hemisphere perceives on its own, but the one influences the other, inhibiting or facilitating particular features to keep the effect harmonious and consistent. It would seem to follow that normally there are in a sense two competent perceivers in each cranium; one, for example, that sees the right and another that perceives the left half of the visual field. One can further fractionate normal consciousness on temporal as well as spatial dimensions as in fatigue states, for example, all with implications of questionable significance so far as scientific analysis is concerned.

The presence of conscious comprehension in a hemisphere is hardly demonstrable in the absence of some mode of expression. If speech and writing are excluded as they are in the minor hemisphere or in other kinds of brain damage, more devious testing procedures are required. One is impressed with the ease with which a patient's intellect and conscious capacity, in general, may be misjudged as a result of defects or losses that may be confined mainly or entirely to the mechanisms of expression.

The conscious awareness of the minor hemisphere produced by this vertical splitting of the brain often seems so remote to the conversant hemisphere as to be comparable in effect perhaps to the situation produced by a spinal transection. It makes one wonder if we can really rule out, as I have implied earlier [Sperry, 1964b], the alternative contention of those who maintain that spinal cords, loaves of bread, and even single molecules have a kind of consciousness. Either way, the inferences to be drawn regarding the evolution and elaboration of consciousness in its various states and the valuation that we can put on its respective manifestations remain, for most practical purposes, much the same.

We are often asked if the disconnected hemispheres must not also have each a will of its own and if the two do not then get into conflict with each other. During the first half year after surgery, particularly with the first patient, we got reports suggesting something of the kind. For example, while the patient was dressing and trying to pull on his

trousers, the left hand might start to work against the right to pull the trousers down on that side. Or, the left hand, after just helping to tie the belt of the patient's robe, might go ahead on its own to untie the completed knot, whereupon the right hand would have to supervene again to retie it. The patient and his wife used to refer to the "sinister left hand" that sometimes tried to push the wife away aggressively at the same time that the hemisphere of the right hand was trying to get her to come and help him with something. Such antagonistic movements were much less a bother in Case II, though they were present in minor degree during the early months after surgery. These conflicting and dissociated movements of right and left hands are pretty well restricted to situations where the reactions of left and right hand are easily made from the same common supporting posture of body and shoulders. Generally speaking, there are so many unifying factors of this kind and others in the situation, and functional harmony is so strongly built into the undivided brain stem and spinal networks by express design, that one does not see much overt expression, or motor overflow into action, at least, of such conflicts between will power-right and will power-left.

This matter of having two free wills packed together inside the same cranial vault in these patients reminds us that free will is one of the most treasured features of the conscious process and also one of its most controversial properties from the scientific and philosophic standpoints.

(This and the following as well as much of the foregoing is taken from an earlier communication [Sperry, 1964b] of the writer, mainly for reason of expediency in the face of a difficult deadline. Use of the earlier discussion has the advantage, however, of showing that the opinions and implications included are not slanted for the present occasion, but represent the ordinary give and take in scientific thinking.)

Unlike *mind, consciousness*, and *instinct, free will* has not made any notable comeback in behavioral science in recent years. Most behavioral scientists will refuse to recognize the presence of free will in brain function. Every advance in the science of behavior, whether it has come from the psychiatrist's couch, from microelectrode recording, from brain splitting, from the use of psychomimetic drugs, or from the running of cannibalistic flatworms, seems only to reinforce that old suspicion that free will is just an illusion like the rise and setting of the sun. The more we study and learn about the brain and behavior, the more deterministic, lawful, and causal it appears.

In other words, behavioral science tells us that there is no reason to think that any of us here today had any real choice to be anywhere else, nor even to believe in principle that our presence here was not already in the cards, so to speak, five, ten or fifteen years ago. I do not

like or feel comfortable about this kind of thinking any more than you do, but so far I have not found any satisfactory way around it. Alternatives to the rule of causal determinism in behavior that I have seen proposed so far, as, for example, the inferred unlawfulness in the dance of subatomic particles, seem decidedly more to be deplored as a solution than desired.

This is not to say that in the practice of behavioral science we have to regard the brain as just a pawn of the physical and chemical forces that play in and around it. Far from it. Recall that a molecule in many respects is the master of its inner atoms and electrons. The latter are hauled and forced about in chemical interactions by the overall configurational properties of the whole molecule. At the same time, if our given molecule is itself part of a single-celled organism like paramecium, it in turn is obliged, with all its parts and its partners, to follow along a trail of events in time and space determined largely by the extrinsic overall dynamics of *Paramecium caudatum*. And similarly, when it comes to brains, remember always that the simpler electric, atomic, molecular, and cellular forces and laws, though still present and operating, have all been superseded in brain dynamics by the configurational forces of higher-level mechanisms. At the top, in the human brain, these include the powers of perception, cognition, memory, reason, judgment, and the like, the operational, causal effects and forces of which are equally or more potent in brain dynamics than are the outclassed inner chemical forces.

You sense the underlying rationalization we are leading to here: "If you can't lick 'em, join 'em." If we cannot avoid determinism, accept and work with it. There may be worse "fates" than causal determinism. Maybe after all it is better to be properly imbedded in the causal flow of cosmic forces, as an integral part thereof, than to be on the loose and out of contact, free-floating, as it were, with behavioral possibilities that have no antecedent cause and hence no reason or any reliability for future plans or predictions.

In line with this, just one more point: If one were assigned the task of trying to design and build the perfect free will model—let us say the perfect all-wise decision-making machine to top all competitor's decision-making machines—consider the possibility that instead of trying to *free* the machinery from causal contact, it might be better perhaps to aim at the opposite: that is, to try to incorporate into the model the potential value of *universal causal contact;* in other words, contact with all related information in proper proportion—past, present and future.

It is clear that the human brain has come a long way in evolution in exactly this direction when you consider what goes on between its input and output in the process of making a decisive response. Consider

just the amount and the kind of information and causal factors that our multidimensional intracranial vortex draws into itself, scans, and may then bring to bear on the process of turning out one of its "preordained decisions." Potentially included, thanks to memory, are the events and the collected wisdom of most of a human lifetime. We can add to this, given a trip to the library, the accumulated knowledge of all recorded history. And to all the foregoing information we can further add, thanks to reason and logic, much of the future forecast and predictive value extractable from all this data, not to mention the creative insights that evolve from the interplay of new constellations of all the foregoing. Maybe the total here falls considerably short of universal causal contact, and maybe it is not even quite up to the kind of thing that evolution has going for itself over on Galaxy Nine, and maybe we must grant, in spite of all, that any decision that does eventually come out is still causally determined. Nevertheless, this kind of thing is, in a sense, a very long jump in the direction of freedom from the original slime mold, the Jurassic or Cretaceous sand dollar, or even the 1964 model orangutan.

Following are some further heterogenous excerpts added from earlier communications [Sperry, 1952, 1964b] and included, here out of context, for their bearing on issues in the problem of consciousness:

> Prior to the first appearance of conscious awareness in evolution, the entire cosmic process, science tells us, was only, as someone has phrased it, "A play before empty benches," colorless and silent at that because, according to our present physics, prior to the advent of brains there was no *color* and no *sound* in the universe, nor was there any flavor or aroma and probably rather little sense and no feeling or emotion. Before brains the universe was also free of pain and anxiety.
>
> All of these conscious phenomena can now be generated by the surgeon's electrode tip applied to the proper regions of the exposed conscious brain. These conscious effects can be triggered also of course by the proper external stimuli, but, more interestingly, by centrally initiated dream states, illusionogenic and hallucinogenic agents. That is, they don't depend on the outside world, but may be generated centrally. But always and only, within and by a brain. There is no more important quest in the whole of science probably than the attempt to understand those very particular events in evolution by which brains worked out that special trick that has enabled them to add to the cosmic scheme of things: color, sound, pain, pleasure, and all the other facets of mental experience.

> In searching brains for clues to the critical features that might be responsible for consciousness, I have never myself been inclined to focus on the electrons, protons, or the neutrons of the brain; nor either on its atoms; and

with all due respect to biochemistry and the N.R.P., I have not been inclined to look particularly at the little molecules of the brain nor even at its big macromolecules in this connection. It has always seemed rather improbable that even a whole brain cell has got what it takes to sense, to perceive, to feel or to think, on its own. The "search for psyche" in my own case at least has been directed mainly at higher level configurations of the brain like specialized circuit systems—and not just any juicy central nerve network that happens to be complex and teeming with electrical excitation. I have been inclined to look rather at circuits specifically designed for the express job of producing effects like pain, or high C, or blue-yellow, circuits of the kind that one finds above a high transection of the spinal cord, but not below —circuits with something that may well be present in the tiny pinhead dimensions of the midbrain of the color-perceiving goldfish, but lacking in the massive spinal cord tissue of the ox, circuits that are profoundly affected by certain lesions of the midbrain and thalamus, but remarkably little altered by complete absence of the entire human cerebellum. And if it actually came to laying money on the line, I would probably bet first choice on still larger cerebral configurations, configurations that include the combined effects of both (*a*) the specialized circuit systems like the foregoing, plus (*b*) a background of cerebral activity of the alert waking type. Take away the specific circuit, or the background, or the orderly activity from either one, and the conscious effect is gone.

It is common observation that destruction of a brain part through disease, trauma, anoxia, etc., commonly leads to an irreversible permanent loss of the corresponding facet of mental awareness with consequent reduction and crippling of the cognitive self. In this and in the many other evidences that consciousness is directly tied to the properly functioning brain mechanism, the student of brain function finds little to encourage the almost universal hope of the human brain for perseveration of something of its perceiving self following cerebral arrest. This is in line with the prevailing view that consciousness is an emergent property of certain specialized cerebral circuits in action, that is, circuits that are living and unanesthetized and engaged in a normally alert form of activity.

For scientists and engineers involved in computer design it has become a not entirely impractical question to ask whether consciousness is necessarily and inevitably tied to *living* hardware. In this connection, I do not see anything in the above view that excludes the possibility that consciousness might be present in a machine or electronic device, provided it could carry out the kinds of objective functions and processes that the brain handles. This is very different, however, from saying that there is an inner conscious aspect to everything.

In fact, I have often thought that a computer with a sense of pain and pleasure, not to mention color perception, hearing, and other feelings

in the conscious introspective sense might well be a much more proficient computer than a similar machine without the conscious properties. For adaptive and complex reactions, consciousness may not be necessary, but when it comes to learning that involves memory, conscious centers become a tremendous asset. This reasoning favors the view that consciousness may have real operational value, that it is more than merely an overtone, a by-product, epiphenomenon, or a metaphysical parallel of the objective process.

If we continue to ask what variables in brain function are correlated with what variables in conscious experiences [Sperry, 1952], and enough of us concentrate our brain research in this direction, the nature of consciousness and its relation to brain process is bound to become increasingly clear. In this day of information explosion it would not be too surprising if some of us present may live to know the full answer.

DISCUSSION

Chairman: LORD ADRIAN

PENFIELD: I think this has been a most startling presentation of these two cases, and it helps to answer certain questions that we have in mind. It is clear that in perception one hemisphere can work with the record of consciousness that is within that same hemisphere, and it is clear, too, that the record of the stream of consciousness is laid down in duplicate in the two sides. This is something that we have always suspected, but as far as I know it has never been proved before; and if I could make a little sketch on the board I can show how this applies to our thinking with regard to the record of the stream of consciousness.

You see here the undersurface of the brain with the midbrain cut across and the cerebellum and pons removed. You see on either side of the midbrain the undersurface of the hippocampus. Now this area is often injured at birth by herniation of the brain through the opening of the incisura of the tentorium. It is squeezed through, and so you have one hippocampus injured, or both, at the time of birth; and we are quite clear that in some of our patients who suffer from temporal lobe epilepsy the cause of the attacks is the scarring of the hippocampus (and often the temporal lobe) produced by the pressure while the baby's head passes through the birth canal. In one distressing case I removed the anterior part of the temporal lobe on the left hoping to cure the attacks, but leaving the hippocampus in place. Then after more than three years, as the patient was not cured, I removed the left hippocampus. He improved as far as attacks were concerned but his memory for recent years was lost [Milner and Penfield, 1955]. Further study led to the conclusion that the right hippocampus had been destroyed at birth. We were forced to conclude that bilateral absence of the hippocampus meant loss of

the memory record. With the hippocampus intact on one side, his memory had been normal. He retains his skill as a draftsman and earns his living, but he cannot recall such things as what he had for breakfast today. It is apparent that the memory record in one side is normally the duplicate of that in the other hemisphere under normal conditions. It is located in the hippocampus, together with its connections in the diencephalon. This would explain the findings in these two cases reported by Professor Sperry.

SPERRY: Attempts to produce similar effects in monkeys and other animals have been rather disappointing, suggesting probably that there have been some rapid changes in the course of primate evolution to make the hippocampal structures so critical in man for recent memory. I assume you do not imply that all memory, including that for language, is laid down on both sides. In this connection, language comprehension, I suppose, must be distinguished from speech; it is the motor expression especially, speech and writing, that is most lateralized. But there seems to be much individual variation in these higher-level functions, that is, in the organization of speech, for example, and the functional organization of the corpus callosum in general, so that what applies to one person may not apply to the next. In a small percentage of the population, you recall, Milner found speech to be bilateralized.

MOUNTCASTLE: I would very much like to know, Dr. Sperry, something about the performance of these patients using auditory input, which you did not say anything about. It would be especially interesting to know what happens when the verbalizing hemisphere provides erroneous information to the other hemisphere which can itself respond correctly to somesthetical or visual input.

SPERRY: We have not run any specific tests on auditory functions—except incidentally where speech is involved. The minor hemisphere will use the speech emanating from the major hemisphere, and this is sometimes a means of effecting a kind of cross-integration; for example, if a familiar sample object is placed in the right hand while the subject is blindfolded, the left hand is unable to pick out by palpation the same or a matching object from among others. However, if the subject is allowed to name out loud the sample object in the right hand, then the left hand does find the correct object. Similarly, the left hand can be used to retrieve an object named aloud by the experimenter. At the same time, remember that if the given object is placed in the left hand or retrieved by the left hand without auditory or other cues accessible to the major hemisphere, then the speech hemisphere is unable to name or otherwise indicate any perception of such an object, which is perceived only by the minor hemisphere.

TEUBER: I would just like to ask a question to clarify my understanding of the description you gave of the second of the two cases. Was there a return of capacity not only to write with the left hand, but also to read simple words in the left half field, or did I misunderstand your presentation?

SPERRY: No, you state it correctly.

TEUBER: I would find that most remarkable in view of the repeated trend to interpret difficulties in object recognition, or rather, object naming, by the left hand to an interruption of the callosal commissure.

SPERRY: You first asked about writing and about visual comprehension and now you are speaking of tactile recognition and naming?

TEUBER: As I understood it, it was the left visual half-field that could recognize the word written and the left hand that could identify the appropriate object.

SPERRY: Let us go through that again slowly, you say that the left hand feels an object or the left field looks at a word?

TEUBER: A word is presented to the left visual field; the left hand feels for the appropriate object and finds it. This is how I understood your statement.

SPERRY: The left half-field can read the name of a familiar object, or the object may be placed in the left hand. Either way, the left hand can then retrieve the corresponding object, using either tactile or visual guidance. That is, we have intermodal transfer here within the minor hemisphere as well as comprehension of the printed word.

BREMER: Did I understand that the alexia in the left half-field, which was a consequence of the callosotomy, disappeared after a short time?

SPERRY: It did in the second patient.

BREMER: It did disappear! That is the reason of Dr. Teuber's surprise and my surprise too.

SPERRY: Yes, but remember that a small percentage of people have rather full bilateralization of speech, and also remember that it is only comprehension we are demonstrating here, not motor expression. This same person cannot speak and cannot write with the minor hemisphere, but she can draw simple pictures. She can write with the left hand, but by testing this with lateralized visual or tactile input, we infer this to be governed through the major hemisphere which, as I mentioned, now has considerable control over the left as well as the right hand. With a pen, for example, placed in the left hand out of sight, she can pick out the correct printed name of the test object and can retrieve it and show how it is used, but cannot write any answer. Only after she is told it is a pen, or after the information otherwise reaches the major hemisphere, can she write the answer.

ANDERSEN: Are the two brain halves asleep and alert and awake at the same time?

SPERRY: As far as we know, yes. We have never seen any lateralization of sleep-waking states.

GRANIT: Did you make the minor hemisphere do any mathematical calculations?

SPERRY: We tried, but unsuccessfully. Apparently the minor hemisphere cannot calculate, even to the extent of doubling the numbers 1 to 4.

SCHAEFER: May I ask if the person had awareness on her dominant side —the feeling of something strange happening—because only such a feeling could indicate to us that something besides that system is still acting and that a second ego was somewhere acting besides that in the dominant hemisphere. And then, in respect of free will, I would strongly suggest that, in this case, we adopt a purely methodological point of view because free will is something that comes out of the introspective judgment of man on his own nature. At the same time you can have a feeling of free will and yet there is

a complete determination as judged from the outside. That is the common experience of psychiatrists, so I feel that we should tell philosophers that free will is a completely subjective thing, which is, I believe, in complete agreement with what you stated before.

SPERRY: Occasionally, in the case of the first patient, especially, there was reference to numbness or tingling in the left arm. This could be explained in terms of slight positive sensory effects from the left side being projected to the major hemisphere, that is, uncrossed projection in the somesthetic pathways. In the visual sphere and in the somesthetic system more generally, the absence of distinct complaints about abnormalities in left-sided sensation or perception is the striking thing. I have been inclined to compare this to the absence of complaints about scotomata from occipital lobe damage.

Yes, I believe your relegation of "free will" to the subjective realm while keeping behavior completely determined from the standpoint of objective study, psychiatric treatment, etc., seems consistent; but, of course, it still obliges one to acknowledge that everything he has done, he had to do and could not have done otherwise in the circumstances.

PHILLIPS: May I try to focus this discussion by referring to a sentence in the printed summary? "Each of the separate hemispheres seems to have its own conscious awareness." Now, as I understand, in the second patient the nondominant hemisphere could be regarded as a computer which can read the word "cup" and then select a cup from a miscellany of objects. Now, was the individual conscious of that? What were the subjective statements of the patient about her ability to perform that act?

SPERRY: I can only go back to the statement that someone made here yesterday—namely, that we tend to infer consciousness by analogy; in people, we accept it and in objects we don't.

PHILLIPS: This individual human subject was able to speak to you, but was not able to make any statement that implied consciousness in her computer, which could read the word and select a cup from a collection of objects.

SPERRY: The minor hemisphere may be likened to an aphasic brain in which the centers for speech and writing have been damaged. When an aphasia is reversible, the subject's account of his memory of the aphasic period suggests he had been conscious even though he had been unable to express himself. That the minor hemisphere in these adult cases will ever be able to recount any of the current experiences seems doubtful.

Consider the effect of a stimulus applied to the forehead of our subject which will then be projected to both hemispheres because of the bilateral cortical representation of head and face. The sensation in each hemisphere is presumably identical with respect to its localization, timing, and its general quality. In other words, there are two similar but separate conscious experiences, one in each hemisphere, and I am not sure but what the same is true under normal conditions with the corpus callosum intact. There is nothing particularly disturbing about such a lack of unity in consciousness if one does not try to make consciousness some kind of entity in itself, instead of a functional property of the brain in action.

GOMES: Your communication of facts is most challenging for me. When the two hemispheres of the brain of an individual are separated, some very significant disturbance in the system of control of actions of the individual must occur. It is even amazing that the individual is able to perform usual actions with the ordinary degree of coordination which you have observed in your patients. I ask you, therefore, what do you observe in purposely contrived cases in which there is a conflict between the two hemispheres? Could not such defects be attributed in principle to the difficulty of control of motor action which the individual with a split brain has? But this is not an alternative to your interpretation of the existence of two separate minds, and sometimes even of two separate wills. I ask you whether this conflict is not apparent and the result rather of this interruption of the normal system of control of motor reactions in connection with visual and other kinds of perception.

SPERRY: I don't at the moment see how this would account for all the results, that is, all the evidence indicating independence of perception, learning, and memory. In regard to motor control, there was in the first few months a strong apraxia of the left hand, indicating, as Professor Bremer pointed out, that the mediation of voluntary activity of the left hand is normally dependent on the callosum, especially where language and language-dependent thinking is involved.

MAC KAY: I am following up Dr. Phillips' question. I am intrigued by the apparent resemblances between the automatisms which Dr. Penfield reported, and the sorts of behavior of which people are unaware when they are concentrating (I mean these split-brain people) on data coming in through one hemispheric system. What I am asking is whether this evidence really justifies us in saying that there are really two minds here. Aren't we all conscious of executing minor automatisms, for instance, raising eyebrows, and so forth, when our mind is concentrating on something else? I remember once talking to someone in my bedroom when intending to change my shirt and finding myself putting on my pajamas in the course of the discussion, because we had gone on talking and I had automatically carried out a routine which I might have done consciously if I had intended. Under those circumstances, we might say whimsically that I had another mind that was trying to make me go to bed or something, but the common-sense description is that I had left some of my learned routines to run because I was attending to something else. Now why should we say that there are two minds in these individuals? Why shouldn't we say rather that they are capable in a way that we are not, because of the corpus callosum, they are capable of attending to part of their hemispheric activity at a time?

SPERRY: Everything indicates that the minor hemisphere has its own sensations, perceptions, and memories and that it is capable of at least a little comprehension and thinking. Also the fact that it can learn would seem important here. In monkey experiments we have found that this learning can proceed concurrently and simultaneously in the disconnected hemispheres, one hemisphere learning the opposite of the other. We have seen a few indications of emotional feeling generated in the minor hemisphere, like a broad smile following the completion of a test task with the left hand, a

smile which the subject was unable to explain verbally; or the reverse, frowning at an incorrect verbal response or an inept performance by the right hand when only the minor hemisphere knew the correct answer!

MAC KAY: Yes, but the kind of model which I will be talking about tomorrow would also show this behavior.

SPERRY: Is there anything then that would not apply just as well to the dominant hemisphere?

MAC KAY: I don't think that either hemisphere is conscious. I don't think that it makes sense to attribute consciousness to cerebral hemispheres. What I am saying is that the person is conscious and there is only one person that is conscious, but he has a split control system, and that he is, therefore, able to pay attention to one half at a time in a way we cannot because of the commissural coupling.

SPERRY: Perhaps this depends on one's definition of consciousness. If you think of it in terms of its simplest elements, the raw sensations like the color red, for example, the colors, sounds, taste, touch, smell, and the like, as I have done, then wouldn't it appear most reasonable to assume the presence of conscious sensation in the minor hemisphere when that hemisphere is selecting correctly one of two colors? Dr. Thorpe has to use similar reasoning when it comes to consciousness in various animal species.

CHAIRMAN: I expect that we are all bursting with questions, but I think it will do us good to keep them in store for a bit and think over the results of this extraordinarily interesting communication.

REFERENCES

BOGEN, J. E., and P. J. VOGEL. Cerebral commissurotomy in man, *Bull. Los Angeles Neurol. Soc.*, *27*, 169–172 [1962].

GAZZANIGA, M. S., J. E. BOGEN, and R. W. SPERRY. Some functional effects of sectioning the cerebral commissures in man, *Proc. Natl. Acad. Sci.*, *48*, Part 2, 1765–1769 [1962].

———. Laterality effects in somethesis following cerebral commissurotomy in man, *Neuropsychologia*, *1*, 209–215 [1963].

———. Observations on visual perception after disconnection of the cerebral hemispheres in man, *Brain*, 88, 221–236 [1965].

SPERRY, R. W. Neurology and the mind-brain problem, *Amer. Scientist*, *40*, 291–312 [1952].

———. Cerebral organization and behavior, *Science*, *133*, 1749–1757 [1961*a*].

———. Some developments in brain lesion studies of learning, *Fed. Proc.*, *20*, Part I, 609–616 [1961*b*].

———. The great cerebral commissure, *Scient. American*, *210*, 42 [1964*a*].

———. *Problems Outstanding in the Evolution of Brain Function*, 1964 James Arthur Lecture on the Evolution of the Human Brain. New York: Amer. Mus. Natl. Hist. [1964*b*].