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The Split Brain in Man

The human brain is actually two brains, each capable of advanced mental functions. When the cerebrum is divided surgically, it is as if the cranium contained two separate spheres of consciousness

by Michael S. Gazzaniga

The brain of the higher animals, including man, is a double organ, consisting of right and left hemispheres connected by an isthmus of nerve tissue called the corpus callosum. Some 15 years ago Ronald E. Myers and R. W. Sperry, then at the University of Chicago, made a surprising discovery: When this connection between the two halves of the cerebrum was cut, each hemisphere functioned independently as if it were a complete brain. The phenomenon was first investigated in a cat in which not only the brain but also the optic chiasm, the crossover of the optic nerves, was divided, so that visual information from the left eye was dispatched only to the left brain and information from the right eye only to the right brain. Working on a problem with one eye, the animal could respond normally and learn to perform a task; when that eye was covered and the same problem was presented to the other eye, the animal evinced no recognition of the problem and had to learn it again from the beginning with the other half of the brain.

The finding introduced entirely new questions in the study of brain mechanisms. Was the corpus callosum responsible for integration of the operations of the two cerebral hemispheres in the intact brain? Did it serve to keep each hemisphere informed about what was going on in the other? To put the question another way, would cutting the corpus callosum literally result in the right hand not knowing what the left was doing? To what extent were the two half-brains actually independent when they were separated? Could they have separate thoughts, even separate emotions?

Such questions have been pursued by Sperry and his co-workers in a wide-ranging series of animal studies at the California Institute of Technology over the past decade [see "The Great Cerebral Commissure," by R. W. Sperry; SCIENTIFIC AMERICAN, January, 1964]. Recently these questions have been investigated in human patients who underwent the brain-splitting operation for medical reasons. The demonstration in experimental animals that sectioning of the corpus callosum did not seriously impair mental faculties had encouraged surgeons to resort to this operation for people afflicted with uncontrollable epilepsy. The hope was to confine a seizure to one hemisphere. The operation proved to be remarkably successful; curiously there is an almost total elimination of all attacks, including unilateral ones. It is as if the intact callosum had served in these patients to facilitate seizure activity.

This article is a brief survey of investigations Sperry and I have carried out at Cal Tech over the past five years with some of these patients. The operations were performed by P. J. Vogel and J. E. Bogen of the California College of Medicine. Our studies date back to 1961, when the first patient, a 48-year-old war veteran, underwent the operation: cutting of the corpus callosum and other commissure structures connecting the two halves of the cerebral cortex [*see illustration on page 26*]. As of today 10 patients have had the operation, and we have examined four thoroughly over a long period with many tests.

From the beginning one of the most striking observations was that the operation produced no noticeable change in the patients' temperament, personality or general intelligence. In the first case the patient could not speak for 30 days after the operation, but he then recovered his speech. More typical was the third case: on awaking from the surgery the patient quipped that he had a "splitting headache," and in his still drowsy state he was able to repeat the tongue twister "Peter Piper picked a peck of pickled peppers."

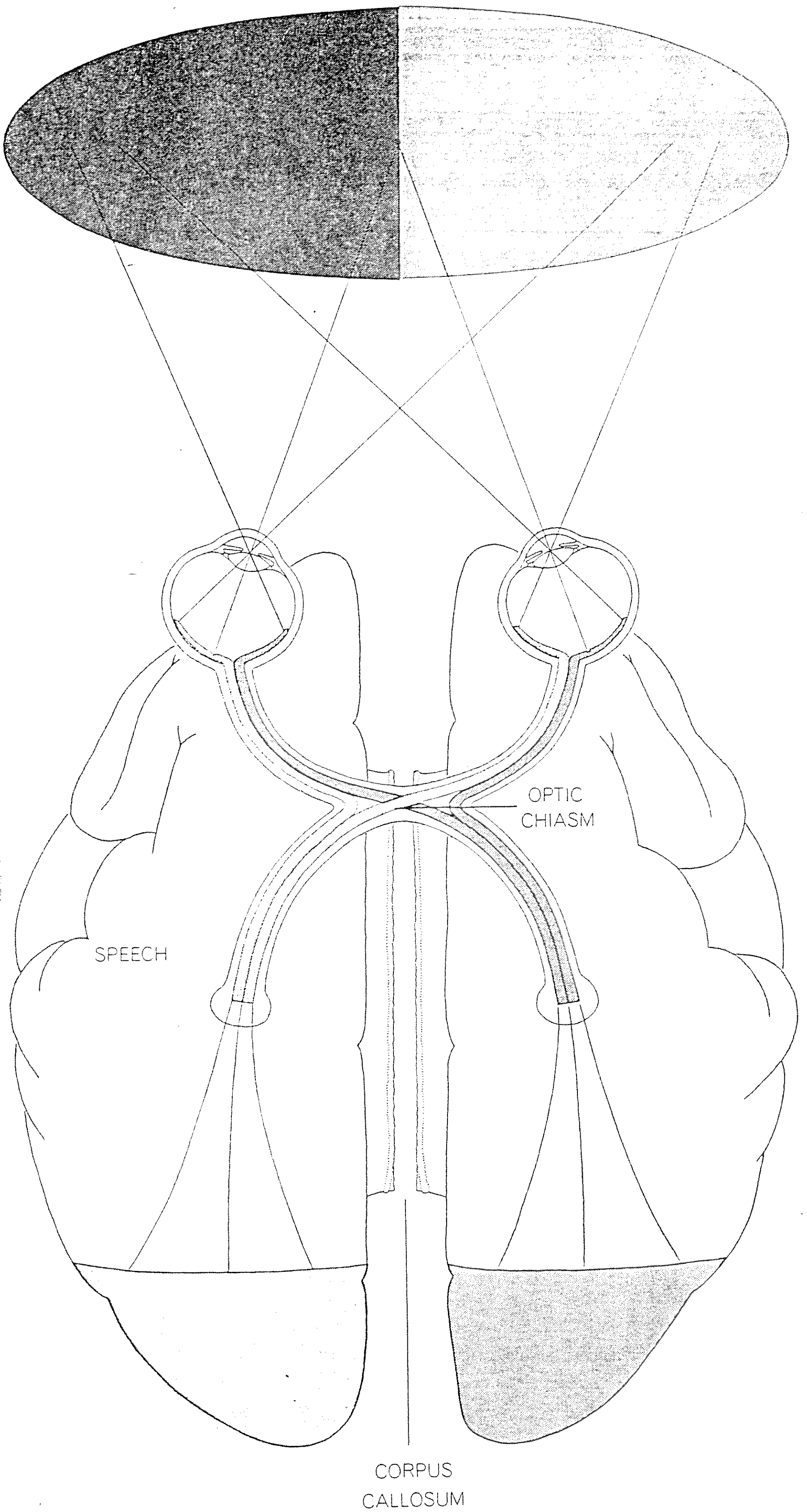
Close observation, however, soon revealed some changes in the patients' everyday behavior. For example, it could be seen that in moving about and responding to sensory stimuli the patients favored the right side of the body, which is controlled by the dominant left half of the brain. For a considerable period after the operation the left side of the body rarely showed spontaneous activity, and the patient generally did not respond to stimulation of that side: when he brushed against something with his left side he did not notice that he had done so, and when an object was placed in his left hand he generally denied its presence.

More specific tests identified the main features of the bisected-brain syndrome. One of these tests examined responses to visual stimulation. While the patient fixed his gaze on a central point on a board, spots of light were flashed (for a tenth of a second) in a row across the board that spanned both the left and the right half of his visual field. The patient was asked to tell what he had seen. Each patient reported that lights had been flashed in the right half of the visual field. When lights were flashed only in the left half of the field, however, the patients generally denied having seen any lights. Since the right side of the visual field is normally projected to the left hemisphere of the brain and the left field to the right hemisphere, one might have concluded that in these patients with divided brains the right hemisphere was in effect blind. We found, however, that this was not the case when the patients were directed to point to the lights that had flashed instead of giving a verbal report. With this manual response they were able to indicate when lights had been flashed in the left visual field, and perception with the brain's right hemisphere proved to be almost equal to perception with the left. Clearly, then, the patients' failure to report the right hemisphere's perception verbally was due to the fact that the speech centers of the brain are located in the left hemisphere.

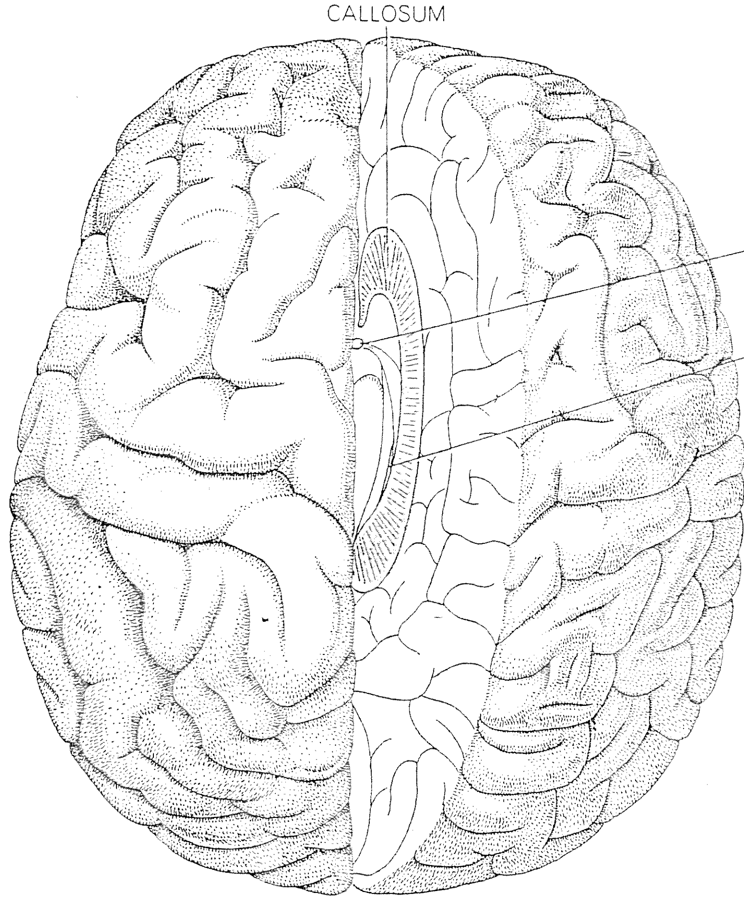
Our tests of the patients' ability to recognize objects by touch at first resulted in the same general finding. When the object was held in the right hand, from which sensory information is sent to the left hemisphere, the patient was able to name and describe the object. When it was held in the left hand (from which information goes primarily to the right hemisphere), the patient could not describe the object verbally but was able to identify it in a nonverbal test—matching it, for example, to the same object in a varied collection of things. We soon realized, however, that each hemisphere receives, in addition to the main input from the opposite side of the body, some input from the same side. This "ipsilateral" input is crude; it is apparently good mainly for "cuing in" the hemisphere as to the presence or absence of stimulation and relaying fairly gross information about the location of a stimulus on the surface of the body. It is unable, as a rule, to relay information concerning the qualitative nature of an object.

Tests of motor control in these split-brain patients revealed that the left hemisphere of the brain exercised normal control over the right hand but had less than full control of the left hand (for instance, it was poor at directing individual movements of the fingers). Similarly, the right hemisphere had full control of the left hand but not of the right hand. When the two hemispheres were in conflict, dictating different movements for the same hand, the hemisphere on the side opposite the hand generally took charge and overruled the orders of the side of the brain with the weaker control. In general the motor findings in the human patients were much the same as those in split-brain monkeys.

We come now to the main question on which we centered our studies, namely how the separation of the hemispheres affects the mental capacities of the human brain. For these psychological tests we used two different devices. One was visual: a picture or written information was flashed (for a tenth of a second) in either the right or the left visual field, so that the information was transmitted only to the left or to the right brain hemisphere [*see illustration on page 27*]. The other type of test was



VISUAL INPUT to bisected brain was limited to one hemisphere by presenting information only in one visual field. The right and left fields of view are projected, via the optic chiasm, to the left and right hemispheres of the brain respectively. If a person fixes his gaze on a point, therefore, information to the left of the point goes only to the right hemisphere and information to the right of the point goes to the left hemisphere. Stimuli in the left visual field cannot be described by a split-brain patient because of the disconnection between the right hemisphere and the speech center, which is in the left hemisphere.



TWO HEMISPHERES of the human brain are divided by neurosurgeons to control epileptic seizures. In this top view of the brain the right hemisphere is retracted and the corpus callosum and other commissures, or connectors, that are generally cut are shown in color.

tactile: an object was placed out of view in the patient's right or left hand, again for the purpose of conveying the information to just one hemisphere—the hemisphere on the side opposite the hand.

When the information (visual or tactile) was presented to the dominant left hemisphere, the patients were able to deal with and describe it quite normally, both orally and in writing. For example, when a picture of a spoon was shown in the right visual field or a spoon was placed in the right hand, all the patients readily identified and described it. They were able to read out written messages and to perform problems in calculation that were presented to the left hemisphere.

In contrast, when the same information was presented to the right hemisphere, it failed to elicit such spoken or written responses. A picture transmitted to the right hemisphere evoked either a haphazard guess or no verbal response at all. Similarly, a pencil placed in the left hand (behind a screen that cut off vision) might be called a can opener or a cigarette lighter, or the patient might not even attempt to describe it. The verbal guesses presumably came not from the right hemisphere but from the left, which had no perception of the object but might attempt to identify it from indirect clues.

Did this impotence of the right hemisphere mean that its surgical separation from the left had reduced its mental powers to an imbecilic level? The earlier tests of its nonverbal capacities suggested that this was almost certainly not so. Indeed, when we switched to asking for nonverbal answers to the visual and tactile information presented in our new psychological tests, the right hemisphere in several patients showed considerable capacity for accurate performance. For example, when a picture of a spoon was presented to the right hemisphere, the patients were able to feel around with the left hand among a varied group of objects (screened from sight) and select a spoon as a match for the picture. Furthermore, when they were shown a picture of a cigarette they succeeded in selecting an ashtray, from a group of 10 objects that did not include a cigarette, as the article most closely related to the picture. Oddly enough, however, even after their correct response, and while they were holding the spoon or the ashtray in their left hand, they were unable to name or describe the object or the picture. Evidently the left hemisphere was completely divorced, in perception and knowledge, from the right.

Other tests showed that the right hemisphere did possess a certain amount of language comprehension. For example, when the word "pencil" was flashed to the right hemisphere, the patients were able to pick out a pencil from a group of unseen objects with the left hand. And when a patient held an object in the left hand (out of view), although he could not say its name or describe it, he was later able to point to a card on which the name of the object was written.

In one particularly interesting test the word "heart" was flashed across the center of the visual field, with the "he" portion to the left of the center and "art" to the right. Asked to tell what the word was, the patients would say they had seen "art"—the portion projected to the left brain hemisphere (which is responsible for speech). Curiously when, after "heart" had been flashed in the same way, the patients were asked to point with the left hand to one of two cards—"art" or "he"—to identify the word they had seen, they invariably pointed to "he." The experiment showed clearly that both hemispheres had simultaneously observed the portions of the word available to them and that in this particular case the right hemisphere, when it had had the opportunity to express itself, had prevailed over the left.

Because an auditory input to one ear goes to both sides of the brain, we conducted tests for the comprehension of words presented audibly to the right hemisphere not by trying to limit the original input but by limiting the ability to answer to the right hemisphere. This was done most easily by having a patient use his left hand to retrieve, from a grab bag held out of view, an object named by the examiner. We found that the patients could easily retrieve such objects as a watch, comb, marble or coin. The object to be retrieved did not even have to be named; it might simply be described or alluded to. For example, the command "Retrieve the fruit monkeys like best" results in the patients' pulling out a banana from a grab bag full of plastic fruit; at the command "Sunkist ils a lot of them" the patients retrieve orange. We knew that touch informaon from the left hand was going exclu-vely to the right hemisphere because oments later, when the patients were ked to name various pieces of fruit laced in the left hand, they were unable score above a chance level.

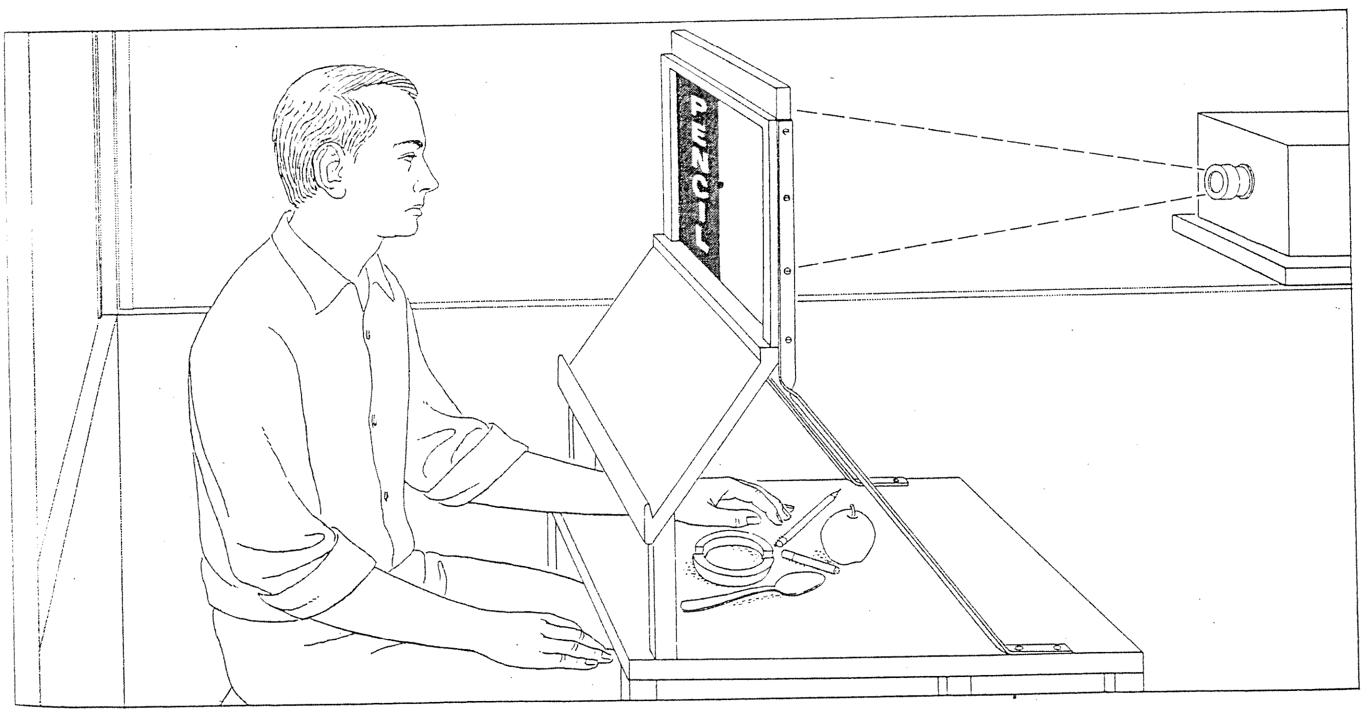
The upper limit of linguistic abilities in each hemisphere varies from subject subject. In one case there was little or evidence for language abilities in the ght hemisphere, whereas in the other ree the amount and extent of the caacities varied. The most adept patient howed some evidence of even being ble to spell simple words by placing lastic letters on a table with his left and. The subject was told to spell a vord such as "pie," and the examiner hen placed the three appropriate letters, ne at a time in a random order, in his eft hand to be arranged on the table. The patient was able to spell even more bstract words such as "how," "what" and "the." In another test three or four etters were placed in a pile, again out of iew, to be felt with the left hand. The etters available in each trial would spell nly one word, and the instructions to he subject were "Spell a word." The paient was able to spell such words as "cup" and "love." Yet after he had completed this task, the patient was unable o name the word he had just spelled!

The possibility that the right hemisphere has not only some language but even some speech capabilities cannot be ruled out, although at present there is no firm evidence for this. It would not be surprising to discover that the patients are capable of a few simple exclamatory remarks, particularly when under emotional stress. The possibility also remains, of course, that speech of some type could be trained into the right hemisphere. Tests aimed at this question, however, would have to be closely scrutinized and controlled.

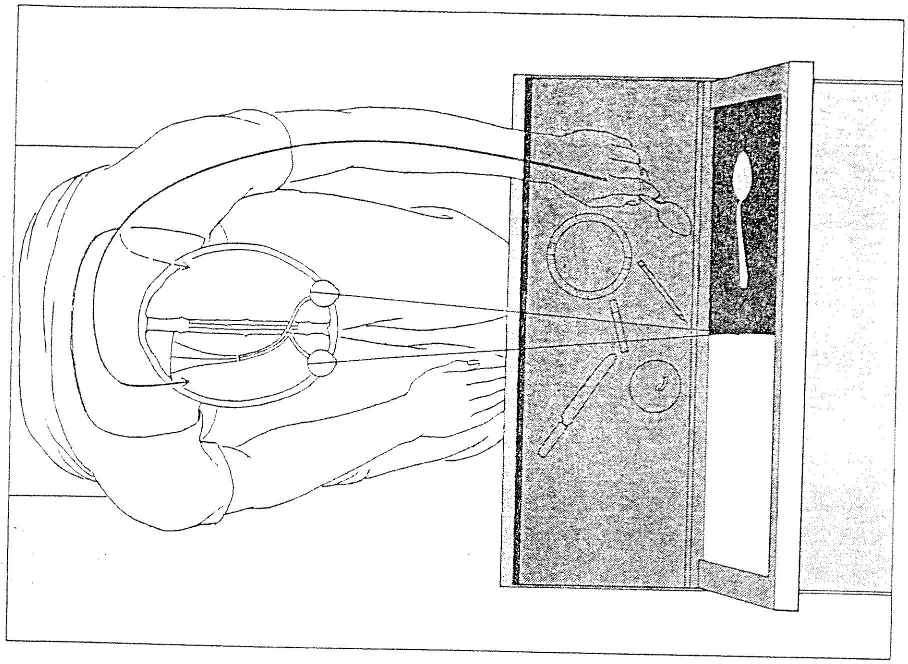
The reason is that here, as in many of the tests, "cross-cuing" from one hemisphere to the other could be held responsible for any positive findings. We had a case of such cross-cuing during a series of tests of whether the right hemisphere could respond verbally to simple red or green stimuli. At first, after either a red or a green light was flashed to the right hemisphere, the patient would guess the color at a chance level, as might be expected if the speech mechanism is solely represented in the left hemisphere. After a few trials, however, the score improved whenever the examiner allowed a second guess.

We soon caught on to the strategy the patient used. If a red light was flashed and the patient by chance guessed red, he would stick with that answer. If the flashed light was red and the patient by chance guessed green, he would frown, shake his head and then say, "Oh no, I meant red." What was happening was that the right hemisphere saw the red light and heard the left hemisphere make the guess "green." Knowing that the answer was wrong, the right hemisphere precipitated a frown and a shake of the head, which in turn cued in the left hemisphere to the fact that the answer was wrong and that it had better correct itself! We have learned that this crosscuing mechanism can become extremely refined. The realization that the neurological patient has various strategies at his command emphasizes how difficult it is to obtain a clear neurological description of a human being with brain damage.

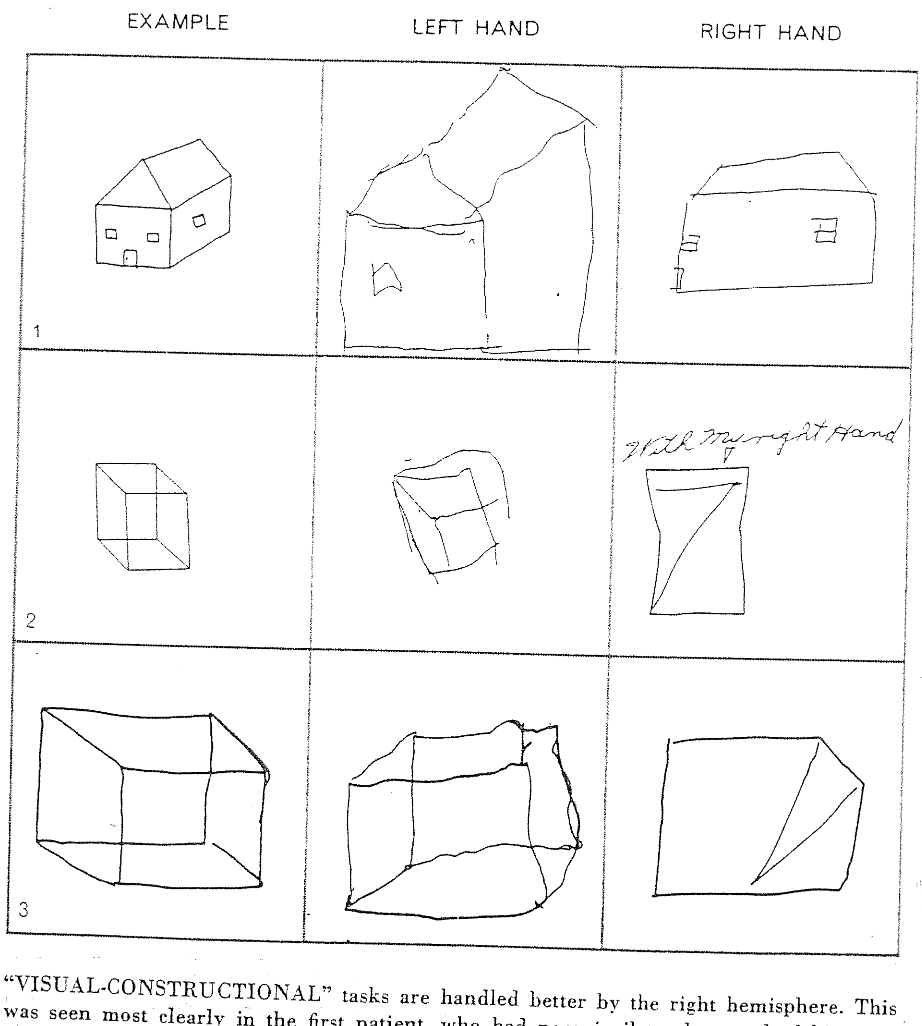
Is the language comprehension by the right hemisphere that the patients exhibited in these tests a normal capability of that hemisphere or was it acquired by learning after their operation, perhaps during the course of the experiments themselves? The issue is difficult to decide. We must remember that we are examining a half of the human brain, a system easily capable of learning from a single trial in a test. We do know that the right hemisphere is decidedly inferior to the left in its overall command of language. We have established, for instance, that although the right hemisphere can respond to a concrete noun such as "pencil," it cannot do as well with verbs; patients are unable to re-



RESPONSE TO VISUAL STIMULUS is tested by flashing a word or a picture of an object on a translucent screen. The examiner first checks the subject's gaze to be sure it is fixed on a dot that marks the center of the visual field. The examiner may call for a verbal response—reading the flashed word, for example—or for a nonverbal one, such as picking up the object that is named from among a number of things spread on the table. The objects are hidden from the subject's view so that they can be identified only by touch.



VISUAL-TACTILE ASSOCIATION is performed by a split-brain patient. A picture of a spoon is flashed to the right hemisphere; with the left hand he retrieves a spoon from behind the screen. The touch information from the left hand projects (*color*) mainly to the right hemisphere, but a weak "ipsilateral" component goes to the left hemisphere. This is usually not enough to enable him to say (using the left hemisphere) what he has picked up.



"VISUAL-CONSTRUCTIONAL" tasks are handled better by the right hemisphere. This was seen most clearly in the first patient, who had poor ipsilateral control of his right hand. Although right-handed, he could copy the examples only with his left hand.

spond appropriately to simple printed instructions, such as "smile" or "frown," when these words are flashed to the right hemisphere, nor can they point to a picture that corresponds to a flashed verb. Some of our recent studies at the University of California at Santa Barbara also indicate that the right hemisphere has a very poorly developed grammar; it seems to be incapable of forming the plural of a given word, for example.

In general, then, the extent of language present in the adult right hemisphere in no way compares with that present in the left hemisphere or, for that matter, with the extent of language present in the child's right hemisphere. Up to the age of four or so, it would appear from a variety of neurological observations, the right hemisphere is about as proficient in handling language as the left. Moreover, studies of the child's development of language, particularly with respect to grammar, strongly suggest that the foundations of grammar—a ground plan for language, so to speak—are somehow inherent in the human organism and are fully realized between the ages of two and three. In other words, in the young child each hemisphere is about equally developed with respect to language and speech function. We are thus faced with the interesting question of why the right hemisphere at an early age and stage of development possesses substantial language capacity whereas at a more adult stage it possesses a rather poor capacity. It is difficult indeed to conceive of the underlying neurological mechanism that would allow for the establishment of a capacity of a high order in a particular hemisphere on a temporary basis. The implication is that during maturation the processes and systems active in making this capacity manifest are somehow inhibited and dismantled in the right hemisphere and allowed to reside only in the dominant left hemisphere.

Yet the right hemisphere is not in all respects inferior or subordinate to the left. Tests have demonstrated that it excels the left in some specialized functions. As an example, tests by us and by Bogen have shown that in these patients the left hand is capable of arranging blocks to match a pictured design and of drawing a cube in three dimensions, whereas the right hand, deprived of instructions from the right hemisphere, could not perform either of these tasks.

It is of interest to note, however, that although the patients (our first subject in particular) could not execute such tasks with the right hand, they were capable of matching a test stimulus to the correct design when it appeared among five related patterns presented in their right visual field. This showed that the dominant left hemisphere is capable of discriminating between correct and incorrect stimuli. Since it is also true that the patients have no motor problems with their right hand, the patients' inability to perform these tasks must reflect a breakdown of an integrative process somewhere between the sensory system and the motor system.

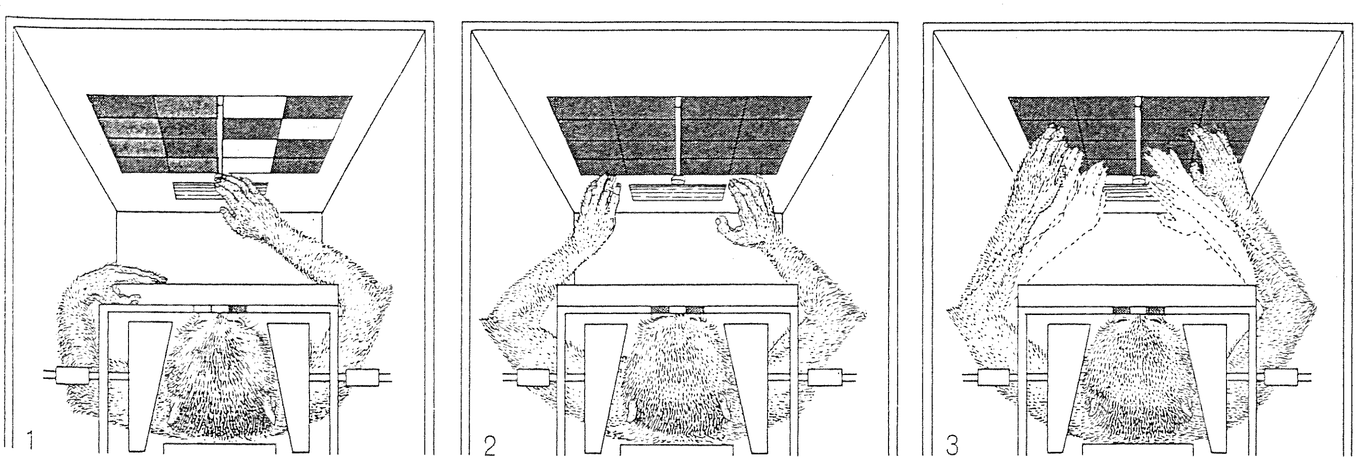
We found that in certain other mental processes the right hemisphere is on a par with the left. In particular, it can independently generate an emotional reaction. In one of our experiments exploring the matter we would present a series of ordinary objects and then suddenly flash a picture of a nude woman. This evoked an amused reaction regardless of whether the picture was presented to the left hemisphere or to the right. When the picture was flashed to the left hemisphere of a female patient, she laughed and verbally identified the picture as a nude. When it was later presented to the right hemisphere, she said in reply to a question that she saw nothing, but almost immediately a sly smile spread over her face and she began to chuckle. Asked what she was laughing at, she said: "I don't know... nothing... oh—that funny machine." Although the right hemisphere could not describe what it had seen, the sight nevertheless elicited an emotional response like the one evoked from the left hemisphere.

Taken together, our studies seem to demonstrate conclusively that in a split-brain situation we are really dealing with two brains, each separately capable of mental functions of a high order. This implies that the two brains should have twice as large a span of attention—that is, should be able to handle twice as much information—as a normal whole brain. We have not yet tested this precisely in human patients, but E. D. Young and I have found that a split-brain monkey can indeed deal with nearly twice as much information as a normal animal [*see illustration below*]. We have so far determined also that brain-bisected patients can carry out two tasks as fast as a normal person can do one.

Just how does the corpus callosum of the intact brain combine and integrate the perceptions and knowledge of the two cerebral hemispheres? This has been investigated recently by Giovanni Berlucchi, Giacomo Rizzolati and me at the Istituto di Fisiologia Umana in Pisa. We made recordings of neural activity in the posterior part of the callosum of the cat with the hope of relating the responses of that structure to stimulation of the animal's visual fields. The kinds of responses recorded turned out to be similar to those observed in the visual cortex of the cat. In other words, the results suggest that visual pattern information can be transmitted through the callosum. This finding militates against the notion that learning and memory are transferred across the callosum, as has usually been suggested. Instead, it looks as though in animals with an intact callosum a copy of the visual world as seen in one hemisphere is sent over to the other, with the result that both hemispheres can learn together a discrimination presented to just one hemisphere. In the split-brain animal this extension of the visual pathway is cut off; this would explain rather simply why no learning proceeds in the visually isolated hemisphere and why it has to learn the discrimination from scratch.

Curiously, however, the neural activity in the callosum came only in response to stimuli at the midline of the visual field. This finding raises difficult questions. How can it be reconciled with the well-established observation that the left hemisphere of a normal person can give a running description of all the visual information presented throughout the entire half-field projected to the right hemisphere? For this reason alone one is wearily driven back to the conclusion that somewhere and somehow all or part of the callosum transmits not only a visual scene but also a complicated neural code of a higher order.

All the evidence indicates that separation of the hemispheres creates two independent spheres of consciousness within a single cranium, that is to say, within a single organism. This conclusion is disturbing to some people who view consciousness as an indivisible property of the human brain. It seems premature to others, who insist that the capacities revealed thus far for the right hemisphere are at the level of an automaton. There is, to be sure, hemispheric inequality in the present cases, but it may well be a characteristic of the individuals we have studied. It is entirely possible that if a human brain were divided in a very young person, both hemispheres could as a result separately and independently develop mental functions of a high order at the level attained only in the left hemisphere of normal individuals.



SPLIT-BRAIN MONKEYS can handle more visual information than normal animals. When the monkey pulls a knob (*1*), eight of the 16 panels light momentarily. The monkey must then start at the bottom and punch the lights that were lit and no others (*2*). With the panels lit for 600 milliseconds normal monkeys get up to the third row from the bottom before forgetting which panels were lit (*3*). Split-brain monkeys complete the entire task with the panels lit only 200 milliseconds. The monkeys look at the panels through filters; since the optic chiasm is cut in these animals, the filters allow each hemisphere to see the colored panels on one side only.