American Handbook of Psychiatry

SPLIT-BRAIN STUDIES

Implications For Psychiatry

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e-Book 2015 International Psychotherapy Institute

From *American Handbook of Psychiatry: Volume 7* edited by Silvano Arieti

Created in the United States of America

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SPLIT-BRAIN STUDIES: IMPLICATIONS FOR PSYCHIATRY[1]

Michael S. Gazzaniga and Bruce T. Volpe

Human Brain Bisection— Present Perspective

Brain science has for the most part been unable to explain the mechanism through which human beings generate a sense of subjective reality. In the past, most of the energy devoted to the problem was spent on considering whether this question could be reasonably studied. Recently, concerns of a more strategic nature have appeared. The neurobiologist approaches the study of mental processes in a reductionist fashion. As a consequence, current discussion of a mental process such as memory is frequently cast entirely in biochemical terms. Although these studies have begun to elucidate the synaptic and cellular events, it is less clear how they promote an understanding of memory, let alone human memory.

The recurring strategic problem that continually plagues biological approaches to psychological processes is the blurred distinction between levels of analysis. This difficulty becomes apparent when we compare the brain to a computer. There is no way the power of a computer algorithm can be deduced by an analysis of the chemical nature of the individual transistors that subserve those functions. The algorithmic functions are a property of the system resulting from the interaction of elements, and they can only be understood at that level.

In this chapter, the objective is to promote an understanding of conscious processes at the level of human behavior. The approach is to examine patients who have undergone brain surgery or who have suffered focal brain damage. The experimental data are derived primarily from patients with progressive intractable epilepsy, who have had a surgical procedure in which the largest inter-hemispheric commissure (the corpus callosum) is sectioned.

First, the early history of human split-brain research will be summarized from the surgical perspective. The neurosurgical procedure is performed only as a final effort to control epilepsy after all drug programs have failed; patients in this group are necessarily few in number. These patients have been followed closely from the therapeutic perspective, but the intensive studies have focused on the cognitive aspects of their course.

Second, it will be demonstrated that the major psychological result of the early studies established that each cerebral hemisphere of the split-brain patient was capable of sustaining autonomous, independent cognitive systems that were outside the realm of awareness of the opposite hemisphere. With language mechanisms generally localized in the left cerebral hemisphere, behavior generated from the right cerebral hemisphere could not, for the most part, be verbalized. Since each hemisphere was ignorant of specific information in the opposite hemisphere, later studies probed the mechanisms by which the integration of these disparate cognitive operations could take place.

Experiments have shown that after a behavior is produced by the nonspeaking (generally right) hemisphere, the subsequent verbal explanation produced by the speaking (generally left) hemisphere delineates an explicit motivation for such activity in spite of the speaking hemisphere having no real prior knowledge of the behavior. Although the model is continuously evolving, it will be argued later in the chapter that an individual is a series of coconscious mental systems each competing for the limited output mechanisms. Of the multiple mental systems present in human beings, usually only one can talk and interpret events linguistically. The view is that the constant flow of emitted behavior is generally interpreted by the verbal system, and provides one with knowledge, opinion, belief about the environment, about oneself, and about one’s behavior. By such acts linguistic behavior provides an organizational framework for the individual.

Finally, the split-brain methodology will be modified for clinical neurological studies of patients with focal brain damage. Similar questions about the interaction of verbal and nonverbal mental systems will be discussed. To date, studies suggest that man is not governed by unconscious and generally immutable belief systems, but that his knowledge, opinions, and beliefs about himself and the world arise out of the need to integrate behaviors that are produced from coconscious nonverbal mental systems.

Perspectives in Neurosurgical History

The neurosurgical operations for the control of intractable epilepsy involve the removal of an abnormal cortical area, the removal of a specific lobe (often temporal or frontal), or, in certain restricted cases, the removal of a complete cerebral hemisphere. Transection of the corpus callosum for epilepsy control dates to the 1940s when Erickson experimented with the spread of seizure activity in the cerebral hemispheres of monkeys. He suggested that the corpus callosum was the principle pathway for the spread of epileptic discharge from one hemisphere to the other, and that severing this commissural system and other forebrain commissures seemed to prevent that spread. Presently, opposing theoretical viewpoints suggest that the presence of the callosum inhibits the spread of seizure activity, but the issue remains unresolved.

At approximately the same time as Erikson, Van Wagenen and Herren independently reached similar conclusions about the importance of the callosum in the spread of the epileptic focus. Their experience was based on clinical observations that epileptic patients who developed tumors of their callosum experienced seizure-free episodes. They took the bold step of performing forebrain commissurotomies on twenty-six patients who suffered intractable epilepsy. Most of the patients underwent partial division of the callosum; only one had the anterior commissure divided. Although the published results of the first ten patients looked optimistic and there was no major change in most patients' behavior, the overall beneficial therapeutic effect was too variable. Nine of the ten patients continued to seize in the first six postoperative months.

An extended follow-up of these patients was undertaken by Akelaitis, who suggested that there was no apparent decrement in mental functioning. Many of the testing procedures that Akelaitis used were clinical in nature, and they were simply not precise enough to address some of the more subtle issues raised by two disconnected hemispheres in the same cranium. Akelaitis concluded that the great cerebral commissure could be sectioned without apparent clinical consequence. However, more sophisticated techniques later revealed the crisp dissociations of independent cognitive processes.

Since the majority of the fibers in the corpus callosum interconnect homotopic regions in the two hemispheres, section of the corpus callosum, reserved as it is for the inexorably progressive forms of epilepsy, differs from the cortical removal operations in that the lesion is clearly restricted to these inter-hemispheric connecting fibers. There is no surround of injury invading adjacent neural areas, such as occurs with cortical ablations. The associated clinically observed deficits are minimal.

In any case, neurosurgical section of the forebrain commissures was not used again until the 1960s when Bogen and Vogel embarked on a new study. Using similar stringent criteria for selecting patients for operation, two new series were begun. Many of these patients experienced fewer seizures, minimal associated clinical changes, and were managed more successfully on lowered drug dosage.

The Human Split-Brain Operation in Transition

From the late 1960s through the early 1970s, Donald Wilson and colleagues of the Dartmouth Medical School started another series of callosal sectioned patients. Using the accepted criteria for the classification of the epilepsies as well as stringent criteria before accepting the patient for surgery, Wilson sectioned the interhemispheric commissures in several different procedures. In the first series, it was standard practice to open the lateral ventricles and divide the anterior commissure, one fornix, and the corpus callosum. In the second series, Wilson continued to use microsurgical techniques, but he did not enter the ventricles; he divided only the corpus callosum. The most recent group of patients, Wilson's third series, underwent similar microsurgical procedures that were completed in two stages. Several weeks elapsed between the first and the second stage of the commissure section. In this procedure the posterior half of the callosum is sectioned, and several weeks later the remaining callosal fibers are sectioned. There are three patients in this study, each of whom has been tested at each stage of commissurotomy.

The History of Cognition in Each Hemisphere

The initial cognitive studies on Bogen and Vogel's- first patients were carried out by Gazzaniga and Sperry. In specific tests, lateralized stimulus information was briefly presented to patients. Most studies involved visual information, although auditory and tactual stimulus presentation modes have also been used. The neural systems that subserve these functions are also discretely lateralized. The visual experiments are possible because the retinal-cortical pathways are organized so that tachistoscopic presentation to the left visual field is projected to the right hemisphere, and information presented in the right visual field is projected to the left hemisphere. In general, only stimuli presented in the right visual field or in the right hand can be verbally identified, since these stimuli are discretely projected to the left hemisphere, whereas both hemispheres can respond in a nonverbal fashion.

The early studies demonstrated that information processed by one disconnected hemisphere was not available to the cognitive apparatus of the other hemisphere. Interhemispheric exchange of information was totally disrupted, so that while visual, tactual, and auditory information presented to one hemisphere could be recorded and processed, and a response could be generated by that hemisphere, these activities occurred unknown to the opposite hemisphere until an overt behavior was produced. The data confirmed the experiments of Myers and Sperry in animals, which showed the callosum to be crucial in interhemispheric transfer. The data in humans, however, were more dramatic: Since the left hemisphere controls the language mechanisms in humans, only processes ongoing in the left hemisphere could be verbally described by the patients.

Thus, if a picture of a spoon, for example, was flashed to the right hemisphere, the subject responded by saying "I did not see anything." However, the subject would be able to retrieve the object with the left hand from a series of objects out of vision (see figure 2-1). The right hemisphere could organize the discrete sensorimotor act of the left hand. Further, when this object was held in the left hand out of the patient's view, the response to the experimenter's question, "What are you holding in your left hand?" would persistently be "I don't know." In fact, the talking hemisphere behaved as if it did not know what the ipsilateral left hand was holding. It did not see the exposed slide, nor did it have access to the highly refined proprioceptive information from the ipsilateral left side of the body. Clearly, however, the right hemisphere was able to process the projected stimulus and initiate any additional activity necessary to direct the left hand to make a correct choice. Since the right hemisphere in all but a very few split-brain patients is not endowed with formal or sophisticated language mechanisms, the process is distinctly nonverbal.

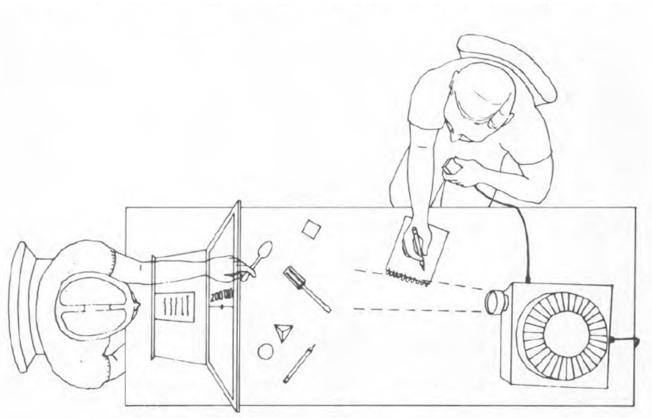

Figure 2-1.
The word “spoon”, lateralized to the left field of a split-brain patient, was available only to his right, nonverbal hemisphere. The patient, unable to name it, was able to retrieve the correct object out of view.

The studies showed that the left dominant hemisphere was vastly superior to the right in both the production and comprehension of language. At the same time, the right hemisphere possessed superior skills on nonverbal tasks such as drawing and copying designs and in arranging items to construct complex patterns. Although each hemisphere appeared to have some bias for processing certain types of information, the detection of this difference depended critically on the experimental design. LeDoux, Wilson, and Gazzaniga showed, for example, that the right hemisphere advantage on a variety of spatial tasks was dependent on the involvement of manual activities in the perception of spatial relationships. In this study the striking difference in the competence of the right compared to the left hemisphere on tasks of spatial relationships disappeared when use of the hands was prohibited. The extension of the early findings of cerebral lateralization has led to broader claims that argue for the presence of different cognitive styles, each existing exclusively within a cerebral hemisphere. The demonstration of the presence of similar cognitive processes in both hemispheres, however, makes the argument for strict lateralization more apparent than real.

Other investigators have asserted that the isolated right hemisphere is the repository for mental processes that are repressed and "unconscious." They suggest that these right hemisphere processes are congruent with primary-process thinking, and that the right hemisphere is the neural substrate of the unconscious, or the generator of some "preconscious stream." Experiments have demonstrated that the right hemisphere can generate an overt behavior in response to specific and complex stimuli. While the stimulus cannot be verbally described, nor the patients able to evince prior verbal knowledge of this behavior, the ensuing act is appropriate to the stimulus. It is doubtful whether stimulus-appropriate behavior out of verbal awareness can continue to be considered "unconscious."

Some specialists have used the notion of right hemisphere as the neural substrate of the unconscious to support a claim that the split-brain patients do not dream, or at least cannot talk about their dreams. Some years ago a study reported that split-brain patients dream. Over the years these patients continued to report their dreams, revealing a fantasy life that is as full and rich as their peers.

The rubrics of “mind-right”—“mind-left,” wholistic mind—analytic mind, intuitiverational, east-west, and so forth, have all been used to describe the differences in cognitive processing between the two hemispheres. Humans seem to seek dichotomies, yet the appeal of these headings or divisions resulted in an impoverished shorthand that has misrepresented the full story. The taxonomy that has been developed for each hemisphere generally ignores important details and, more specifically, the major issue—the study of integrated behavior.

By demonstrating that information could be accurately processed independently in each hemisphere, the early studies introduced the intriguing question of whether the mechanisms of consciousness were doubly represented following split-brain surgery, f While the conscious properties of the speech-producing hemisphere were apparent, the view that the mute and apparently functionless hemisphere was also “conscious” was widely criticized and generally rejected. The task, then, was not only to tease out the workings of a speechless hemisphere and recognize its coconscious status, but also to discover the contribution of this hemisphere to the total behavior of the patient.

Integration of Coconscious Mechanisms in the Split Brain

In recent years this challenge has been answered by designing experiments that focus on the interaction of the two cerebral hemispheres in the split-brain patient. This interaction produces an ever-present sense of unity, even though the experimental evidence clearly shows that the mental phenomena of one hemisphere continue unperceived by the other hemisphere. A series of experimental paradigms address the question of how the dominant left hemisphere deals with the overt and covert behaviors produced by the right hemisphere.

A patient, P, was asked to select from a series of picture cards the one picture that best related to a flashed stimulus. The test picture was flashed tachistoscopically to the right or left visual field and thereby lateralized to the left or right hemisphere. For example, when an "apple" was flashed to a single visual field, the subject was asked to choose from a series of picture cards that might have included a comb, a toaster, and a banana. With the superordinate concept being, in this situation, "fruit," each hemisphere usually made the correct choice. The performance across several superordinate categories was nearly perfect.

To examine how the left, talking hemisphere dealt with behavior produced by the right half of the brain, this experiment was modified slightly: Two pictures were flashed simultaneously, one to each hemisphere. In these critical trials, the patient was again required to point to cards that best related to the flashed stimuli. Only rarely did the response to one of the stimuli, mainly the right visual field-left hemisphere, block a response from the other hemisphere. In general, exposure to both visual fields led to the correct choices. A typical example: A snow scene was exposed to the right hemisphere, and a picture of a chicken claw to the left hemisphere. The best choice for the left hemisphere from the four proffered cards was a chicken, and the best choice for the right hemisphere was a snow shovel. The corresponding choices were made with the hand contralateral to each exposed hemisphere (see figure 2-2).

After the patient had pointed to two out of the eight cards, he was asked to explain the reason for each choice. In the snow scene-chicken claw exposure, the patient explained his choice of a shovel and a chicken by saying, “Oh, that’s simple. The chicken claw goes with the chicken, and you need a shovel to clean out the chicken shed.”

In test after test, when each hemisphere was given a task to solve requiring an overt and specific response, the left language system behaved as if it viewed the overt behavior of both hemispheres and instantly incorporated that behavior into a general theory of personal motivation. The mode of this incorporation was quite specifically elucidated by the left hemisphere language system. However, the verbal system never admitted to prior knowledge of plans or responses generated by other systems, specifically right hemisphere responses. The striking ease and speed with which a story was completed on this and other occasions demonstrated the need of the organism to establish a framework in which the verbal system defended its sense of conscious unity. Once a behavior was manifest the verbal system explained the external reality.

In other tests, patient J was asked to view two pictures simultaneously exposed, one to each visual field. He then had to choose the identical objects from a box of many objects, all within his field of vision. For example, a spoon was exposed to the right hemisphere, and an apple was exposed to the left, speaking hemisphere. He would pick up the spoon with his left hand and then say, "This isn't right. I didn't see a spoon, I saw an apple." This said, he easily moved to the apple and picked it up (see figure 2-3). When asked why he picked up the spoon first, he immediately replied, "It was in the way and I wanted to move it so I could pick up the apple." The explanations for his choices took this line throughout the entire experiment. The responses were neither guesses nor the beginning of vivid confabulations; they were statements of fact, a left hemisphere verbal offering to explain a behavior arising from motivations lurking in the right hemisphere. The left hand would always initially pick out the object flashed to the right hemisphere, and the robust left hemisphere verbal system would immediately suggest several reasons for picking an object that the right hemisphere saw but could not describe.

Figure 2-2.
Two different picture completion tasks were presented simultaneously, one to each hemisphere. The patient was required to point to the appropriate answer, with the hand contralateral to the exposed hemisphere. After both hands moved to complete the task, the patient described the reasons for each choice, even though he could not verbally identify the left visual field.

Source: Gazzaniga, M.S. and LeDoux, J.E. The Integrated Mind. New York: Plenum Press, 1978. p. 149.

After several trials of this kind, in which the left hemisphere was forced to propose a theory for behaviors produced by independent right hemisphere behaviors, J became agitated. In these particular tests an explicit conflict was induced in the patient, since the right hemisphere was basically listening to a "lie" constructed by the left hemisphere. The right hemisphere knew why the left hand was picking up the spoon. It saw a spoon. However, in J this right hemisphere mental system, as is usually the case, was not capable of speech, and it simply was unable to correct the left hemisphere story.

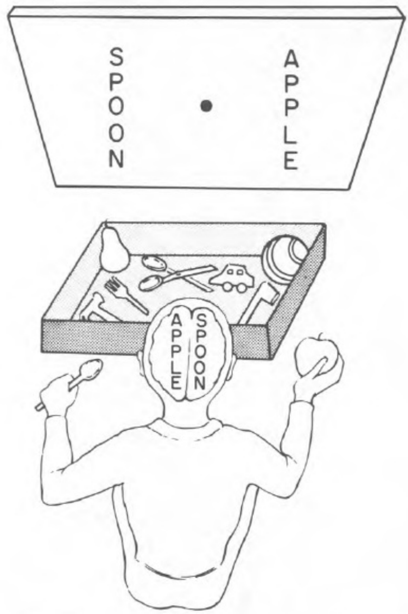

Figure 2-3.
Two different pictures were presented simultaneously, one to each hemisphere-for example, a "spoon" was exposed on the left visual field and an "apple" was exposed on the right visual field. Although the patient chose the correct objects, the left verbal hemisphere did not know why each object was picked. However, the patient immediately offered an explanation.

A re-explanation of the neurosurgical procedure has always had a calming effect on J. Further, a discussion of the possible reasons for the patient's performance on each of the tasks considerably reduced the patient's anxiety. The patient was always reminded of the artificial system of lateralizing the stimulus; it is a situation that never occurs in daily experience. The investigator might say, "It is our special way of testing that presents pictures to your silent right hemisphere that you simply cannot verbally explain."

Yet on the very next trial, J returned to the typical explanation of the overt behavior produced by the right hemisphere response. He never used his awareness of having a disconnected hemisphere to explain his action. In fact, it can be said that after an action, the immediate drive for consistency and coherence through a verbal description is overwhelming. Patients never use the offered alternative explanation for the overt behaviors that occur outside of verbal awareness. The ability to accept the alternative explanation may require a tolerance of the disparate mental systems that is difficult to acquire. The patient's description of reality seems to arise again and again from considering an overt behavior.

Covert Interactions: Cognitive and Emotional Contributions to Consciousness

The variety of phenomena just described have demonstrated how overt behaviors organized by the right hemisphere were accepted and interpreted by the left hemisphere. Consequently, it is necessary to consider how covert behaviors produced by nonverbal mental systems are interpreted by the verbal system. Under certain conditions behavioral responses have demonstrated insight into cognitive-emotional interactions and reinforced the coconscious multiple-mental-system-interaction model. Before describing split-brain experiments carried out to date, it might be helpful to consider some of the current theories of emotional behavior.

Views of emotional mechanisms and their influence on behavior evolved from a controversy between James and Cannon. James argued that the somatic change that occurred following an exciting stimulus was the emotion. Cannon's refutation was based on the physiology of the peripheral visceral changes as observed in animal experiments. According to Cannon, visceral changes were too slow and too nonspecific to account adequately for emotional change. In fact, in animal experiments, total separation of the viscera from the central nervous system did not alter emotional behavior. Peripheral somatic change caused a general but nonspecific state of arousal.

However, a different and more recent view concerning emotional mechanisms has been constructed by Schachter. After long series of experiments, Schachter maintained that the particular cognitive state of a subject determined the emotional interpretation given to a neutral but arousing physical stimulus. Stated differently, cognitive systems establish dimensions for the crude physiological arousal system that in itself cannot determine positive or negative emotion.

More recent and compelling views stem from the work of Zajonc. In his analysis emotional responses are immediate, precede cognition, and suggest a positive or negative value. These emotional responses, in one experimental setting, were based on stimulus frequency. While being exposed to a random series of words, subjects attached more positive ratings to the more frequently presented words. In this experiment, the words that were repeated with greater frequency were also presented so that they could not be verbally detected. Taken as a whole, this argues for the primacy of affect in cognitive-emotional interactions; it also suggests that people initially assign either positive or negative value to a stimulus and that this judgment takes place independent of cognitive analysis.

Studies carried out on cognitive emotional interactions in the split-brain patient support the latter interpretation and also suggest that a nonverbal mental system making a value judgment about the flashed stimulus can subsequently precipitate an emotional state that the left language system is compelled to interpret. The induced emotional state in the split-brain experiments did not lead to any overt behavior that the left hemisphere could observe and interpret. These conclusions are deduced from the following experiments.

It was known from past observations that the right hemisphere of patient P could perform certain primitive language operations. The development of language skills in the right hemisphere is most unusual, and is the subject of another complete investigation. On a verbal command test, P was instructed to perform the action described by a word flashed before him. His reaction to the left visual field presentation of the word “kiss” proved revealing. Although he could neither describe the word he had seen nor mime the activity, he said, . . no way, no way. You’re kidding.” His smile and nervous laugh on this trial was different from those on other trials. He seemed embarrassed by this flash. On presentation of the word “kiss” to the right visual field (left hemisphere), he would not perform the action and, like the adolescent boy he was, he said, “Kiss . . . No way. Kissin’ is not for me.” In trials to both hemispheres there was an emotional reaction to the word “kiss.” In the latter instance, P could accurately describe the word and the action that he was not going to mime. When the command was exposed to the right hemisphere, he responded with an emotional judgment generated by right hemisphere mechanisms, which he could not describe, but he certainly felt. This independent setting of behavior for an emotionally arousing stimulus has led to a broad exploration of independent hemispheres—specifically, whether each half brain would behave as if it had its own independent system for assigning values to events, setting goals and response priorities.

Since this unusual young man, P, could read in the left visual field, it was possible to pursue the right hemisphere responses that were covertly communicated to both hemispheres and that necessitated verbal interpretation by the left hemisphere. In a series of experiments a dozen words that were known to have positive or negative affective quality were singly presented to P's left visual field. The patient's task was to rank order each word by pointing to one of five ratings: like very much, like, undecided, dislike, and dislike very much. The patient's inability to describe verbally the stimulus lateralized to the left visual field confirmed the notion that the left hemisphere did not have access to the complete critical identification of the information. On specific exposures in the right visual field, the verbal response indicated that the left hemisphere could easily perform the task. However, since the experiment addressed the interaction between the hemispheres caused by the emotional content of the stimuli, the critical exposures were to the left visual field. Once this profile of rank order had been established for the right hemisphere by pointing to rating cards, the words were rearranged and again presented to the right hemisphere. In this series of trials, however, the patient was required to make a verbal response. This verbal response emanated from his left hemisphere and indicated a left hemisphere interpretation of the feeling his right hemisphere had about each stimulus.

As can be seen in figure 2-4, the results under the two test conditions were astonishingly similar. The profile of emotional values that the right hemisphere had independently generated and reported by pointing with the left hand was almost identical to the left hemisphere spoken responses to the same set of left visual field stimuli. The left hemisphere on any particular trial was unable to say what the word had been, although it produced identical rankings. Clearly the emotional dimension was communicated to the left hemisphere.

In the context of interactive coconscious mental systems, these results demonstrated how a nonverbal mental system could precipitate an emotion. Furthermore, it showed that once covert behavior is communicated throughout the brain, it is then incorporated into the ongoing verbal interpretation of the present.

A Model for Anxiety: Further Covert Actions

It is clear from observations made some time ago that each disconnected hemisphere of a split-brain subject can independently express emotion. It would seem possible, therefore, that each hemisphere might possibly evaluate a particular stimulus differently. At a particular moment in time, the left might like a particular idea, concept, or person, while the right might react differently.0

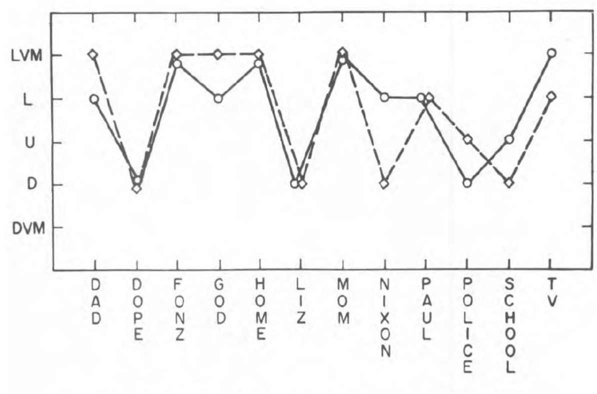

Figure 2-4.
The left hemisphere and the right hemisphere independently ranked a set of emotional words. These nearly identical rankings suggest that emotional values can be shared by two disconnected hemispheres. The scale consisted of: LVM = like very much; L = like; U = undecided; D = dislike; DVM = dislike very much.

Source: Gazzaniga, M.S., and LeDoux, J.E. The Integrated Mind. New York: Plenum Press, 1978, p. 153.

What would be the overall behavioral consequence of this disparate state? Observations of this kind of problem came about on two different test sessions. On a day when P was calm, tractable, and appealing, his left and right hemispheres behaved as if they agreed on, and equally valued, himself, his friends, and other matters (see figure 2-4). Assigning values, generating choices, and making judgments were cognitive tasks easily and independently accomplished by each hemisphere.

At other times, however, there were marked differences between the evaluations made by each hemisphere. Under these circumstances, P behaved in an unusual agitated, aggressive, and restless manner. The right and left hemispheres were producing conflicting evaluations about the same stimuli. It was as if both positive and negative emotional systems were simultaneously active, and the ensuing conflict produced a state of anxiety. In fact, P experienced cold, tremulous extremities, rapid pulse, and dilated pupils—somatic changes frequently associated with anxiety.

This clear example of surgically produced psychological dynamism, seen for the first time in P, raised the question of whether such processes are active in the normal brain. Perhaps most or all episodes of anxiety are the result of discrete mental systems evaluating the same external stimuli or internal thought and assigning different values. Thus, when a nonverbal mental system responds to a particular visual, auditory, sensory, olfactory, or gustatory stimuli, which may or may not enter verbal awareness, it has a pervasive effect on all subsequent processes. These sensations may be conditionally associated with a definite emotional tone so that only a subtle aspect of the experience is necessary to trigger the entire emotional experience. While such conditioning is possible, it need not be available for verbal awareness. For example, in Florence one can be focused on Michelangelo’s statue of David and feel so aroused, awed, and inspired that, unknown to the verbal system, the brain is also recording the scents, noises, and the total gestalt of the city itself. The emotional tone conditioned by these subtle aspects of the experience might later be triggered in other settings because of the presence of similar or related stimuli. The person, puzzled by his affective state, might question the reasons for feeling a certain way. At this point, if the multiple nonverbal representations of the city are not recalled, the verbal system might take over and concoct a substitute, though plausible, explanation. In short, the environment has ways of planting hooks in our minds, and while the verbal system may not know the why or the wherefore, part of its job is to make sense out of the nonverbal mental system interaction.

Partial Commissurotomy: Evidence for Multiple Representational Systems

The remarkable split-brain findings of the past twenty years are not apparent in patients who have undergone section of the anterior one-half to two-thirds of the corpus callosum. However, patients with posterior section of the callosum are usually visually split and produce many of the remarkable behaviors already described in patients with complete callosal section. These clinical situations have generally occurred after tumor removal. This evidence supports a wealth of observations from animal experiments and suggests that disruption of visual communication underlies an important part of the split-brain phenomenon. Recently, Wilson has carried out the surgical process in two stages, with a patient undergoing isolated posterior callosal section that included the splenium. This patient, J, had been examined both pre-and postoperatively. He easily named the exposures in the right visual field (above

91 percent) and pointed accurately to the correct choice after left visual field exposure (also in the 90 percent range). Much of the additional experimental work addressed the psychological quality of the developing ability to name the left visual field exposures.

In brief, the left hemisphere's ability to name different sets of visual stimuli presented to the right half brain, following the selective posterior callosal section, improved during the ten-week period that elapsed between the two surgical procedures. While the first testing session revealed that J was, for the most part, unable to name stimuli presented in the left visual field (28 percent accuracy), he was able eight weeks later, with new stimulus material, to name 83 percent of left visual field stimuli. At first glance, this kind of result might best be explained by hypothesizing that the stimulus presented to the right hemisphere (left visual field) had been transferred by the remaining commissures to the left hemisphere for analysis and naming. Subsequent careful analysis of each test trial argued against that mechanism. When instructed to name the left visual field, J's behavior was unlike any patient with complete callosal section, particularly because he did not deny having "seen" anything. Also unlike patients who have had complete callosal section but who transfer information via the remaining anterior commissure, he did not name the stimuli immediately.

In fact, his initial response after left visual field exposure was to say that he could “see” a “picture” of the stimulus but he could not name it. The examiner initiated a series of questions whenever J insisted that he had some sense of the left visual field information. This interaction often began with the question, “Is it an object or a living thing?” and continued along these lines. Thus, when a line drawing of a hunter’s cap was flashed to the right hemisphere, J reported that the stimulus was an “object.” A number of object classes, such as vehicles, tools, and so on, were then presented. He rejected each, saying “No,” until clothing was offered. At this point he responded with an emphatic “Yes.” He then recognized that the object was worn by a man, and the particular season in which it was worn. When he recognized the usual (red) color, he quickly exclaimed, “hunting cap.” In this manner, J rarely identified the left visual field stimulus immediately. More often he described personally relevant contexts in which the stimulus could be found, yet he guessed infrequently. His choices were precise, and once made, he could not be shaken from his conviction.

It would appear that the stimulus projected to the right hemisphere activated a set of associations that were processed in more anterior regions of the right hemisphere and that were still interconnected by the anterior callosum. Once these attributes were collected, the left verbal system seemed able to deduce what the actual stimulus might have been. This result was more remarkable when particular word-stimuli were considered. To a word exposed in the left visual field—for example, “ship”—he said, “I see a picture of a television show called the *Love Boat,* but it's not boat, ship was flashed." The absence of synonymous substitution errors suggested that the left hemisphere had based the inferential process on more than a pictorial referent.

These and other examples provide converging evidence that the splenium is crucial for interhemispheric visual communication. Moreover, the partial surgical section suggested that the interaction of the verbal and nonverbal mental systems was considerably aided by the construction of complex spatial contexts. The right hemisphere acted to process a visual stimuli not only by pointing to matching choice cards, or completion cards, but also by constructing some representation that became accessible to the verbal system of the left hemisphere.

The Parietal Lobe in Man: Access to the Verbal System After Focal Brain Damage

Although the split-brain patient represents an explicit instance of the interaction of multiple coconscious mental systems, this concept remains to be tested in other situations. The notion of multiple coconscious mental systems can be studied in another clinical neurologic setting. It is generally thought that lesions of the right parieto-occipital cortex in man produce a variety of behavioral disturbances that interfere with the detection of and orientation to external stimuli. A striking example, called "visual extinction," occurs when stimuli are presented simultaneously to both the left and right visual field, and the patient with right parietal damage can identify only the right visual field. Presentation of a single stimulus in any area of the visual field results in accurate detection and description, but simultaneous presentation of two stimuli, one in each field, results in the verbal description of only the stimulus in the right visual field. Although the extinguished stimulus in the left visual field often goes completely unnoticed by these patients, they are able to perform an interfield comparison task between this stimulus, which they cannot name, and the stimulus in the right visual field, which they can name. That is, these patients can make accurate judgments about the similarities or differences between two stimuli, one in each visual field, even though they cannot identify both stimuli and, at times, even deny the presence of the left visual field stimuli.

The results have been documented on seven patients with right parietal damage and on an eighth patient with left parietal damage. Specifically, each patient sat in front of a screen and was required to identify objects or words projected singly to either visual field (see table 2-1). In a second series, stimuli were presented simultaneously to both visual fields, but the response requirements changed. Instead of having to identify both stimuli, the patients were asked to judge whether the stimuli were the same or different. The patients uniformly made accurate judgments when comparing information simultaneously presented to both visual fields, yet on further questioning they were unable to verbally characterize the left visual field information with the same level of accuracy as that of the right visual field (see table 2-2). In fact, during the bilateral simultaneous projections, two patients could not name any of the left visual field stimuli and insisted the task was “absolutely silly,” although they continued to make accurate “same/different” judgments. These data bear on the interaction of verbal and nonverbal mental systems. Similar to the split-brain patients, these patients were influenced by information they frequently were unable to verbally identify.

In the trials where the same stimulus was presented to each visual field, the patient concluded, “Well, that was same, and I saw an apple [nodding toward the right visual field] ... so I guess there was an apple here too [pointing to the left visual field], but I did not see it.” On the majority of “different” trials they generally could not name the stimulus in the visual field that projects to the damaged hemisphere.

The stimulus comparison task appears to occur at a post-perceptual, preverbal level. Only the comparison and not the specific identification is available to linguistic mechanisms (see figure 2-5). In spite of defective orientation to, and detection of, external stimuli, these patients were able to process stimulus information to permit accurate comparison judgments. Their striking inability, in most instances, to acknowledge the presence of that stimulus supports the notion of coconscious mental systems that function out of verbal awareness.

Further Examination of Information Access to the Verbal System

Intracarotid injections of amobarbital are commonly used to investigate the neural substrate for language and memory mechanisms when neurosurgery on the temporal lobes is contemplated. This short-acting barbiturate selectively abolishes half-brain function for a short period of time. In conjunction with this diagnostic effort, experiments have been carried out during the typical test procedures. Prior to the amobarbital test the patient was required to name common pictures and to name objects that were explored tactilely out of the field of vision. When correctly completed these tests signaled adequate processing of visual and tactile information from both visual fields and from both hands. Left visual field information and left-hand information needed further relay to the left hemisphere for naming to occur.

Table 2-1 Single Visual Field Naming

RIGHT PARIETAL LOBE DAMAGE

PATIENT	VISUAL FIELD	
LEFT	RIGHT	
1	1.00 (15)	1.00 (12)
2	0.94 (16)	0-89 (9)
3	0.86 (14)	1.00 (15)

4	0.91 (33)	0.88 (33)
5	0.77 (26)	0.83 (24)
6	1.00 (30)	1.00 (30)
7	1.00 (10)	0.80 (10)

LEFT PARIETAL LOBE DAMAGE

PATIENT	LEFT	RIGHT
1	1.00 (10)	0.80 (10)

The proportion of trials that were correctly named by each patient in each visual field is shown. Numbers in parentheses represent total number of trials presented to each visual field. Variability in the numbers of trials among the patients reflects primary concern for their medical care. Performance differences between the visual fields were not significant (t (7) = 0.833, P -3).

Table 2-2 “Extinguished” Visual Field Naming After Same/Different Judgments on Double Simultaneous Visual Field Presentation Trials

RIGHT PARIETAL LOBE DAMAGE

SAME/DIFFERENT LVF NAMING ON

PATIENT JUDGMENTS “DIFFERENT” TRIALS

1	1.00 (17)	0.00 (7)
2	0.88 (26)	0.00 (16)
3	0-95 (39)	0.48 (25)

4	0.90 (68)	0.23 (35)
5	0.90 (30)	0.32 (19)
6	0.96 (48)	0.38 (24)
7	0.80 (40)	0.18 (40)

LEFT PARIETAL LOBE DAMAGE

SAME/DIFFERENT RVF NAMING ON

PATIENT JUDGMENTS “DIFFERENT” TRIALS

O.80 (40) O.18 (40)

The proportion of correct same/different judgments and proportion of different trials in which the stimulus in the ‘extinguished’ field was correctly named are shown. Numbers in parenthesis represent the total number of trials. The accuracy of the same/different judgments was significantly greater than the accuracy of naming the extinguished field (t (7) = 10.935, P -005)-LVF = left visual field; RVF = right visual field.

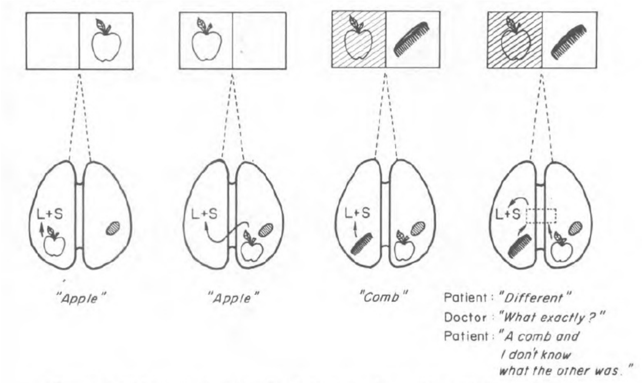

Figure 2-5.
This picture is a series of typical responses from patients with right parietal lobe damage. Under single-field conditions, objects in each visual field were accurately described, but under bilateral presentation, the left visual field object could not be named even though the patient made an accurate "same/different" judgment.

SOURCE: Volpe, B.T., LeDoux, J.E., and Gazzaniga, M.S. "Information Processing of Visual Stimuli in an 'Extinguished' Field," Nature, 282 (1979): 723.

Generally, visual and tactile stimuli were presented to the uninjected and conscious hemisphere during the brief period of depressed functioning of the opposite hemisphere. Reversible paralysis of the contralateral limbs signaled the depressed function of the injected hemisphere. When the effects of the drug had ceased, recall or recognition of the relevant stimuli were assessed. Past studies have demonstrated that memory, specifically for verbal material, was impaired only following injections of the left hemisphere, whereas successful memory for nonverbal material did not lateralize.

Recent laboratory studies have explored the memory for information that exists independent of language. Ten patients, none of whom had aphasia or cognitive deficits prior to testing, were subjected to angiography and carotid amytal testing. Seven patients were tumor suspects, two had isolated seizure foci, and one had already undergone aneurysm repair. The left hemisphere was anesthetized, and the expected right body paralysis and global aphasia in each of the eight patients was produced. Then, an object, say, a spoon, was placed in the left hand. After several moments of palpation the spoon was removed. A few minutes later, the drug effect dissipated and the patient was completely awake, alert, and had full sensorimotor function. When the patient was asked, “What was placed in your hand?” all eight patients responded, “I don’t know,” or “Nothing.” All patients responded accurately, however, on a test of verbal recall from a period prior to the injection, yet no amount of encouragement or cues prompted a verbal description of the palpated object.

When several choice cards were placed in front of the patients, they pointed, almost instantly, with the left hand to the picture of the correct object (see figure 2-6). This performance reflected the inaccessibility of the nonverbal mental system information to verbal analysis. Six of the eight patients pointed to a picture of an object they had palpated while language mechanisms were selectively depressed, although they could not name this object until after they performed the visual choice task. In a similar fashion, two additional patients were required to palpate objects with the left hand while the left hemisphere (and language function) was temporarily depressed. When the drug effect waned they could not verbally describe the palpated object. In spite of this apparent verbal ignorance, they explored, out of vision, a box full of objects, and with the left hand chose the correct object.

Figure 2-6.
During a sodium amytal test, the patient's left hemisphere was anesthetized, and the left (right hemisphere) was allowed to palpate an object. After the drug effect dissipated, the patient was unable verbally to describe the object, but he was able to retrieve it with the left hand.

These data suggest that information stored in the absence of language was not easily accessible to language, even when that nonverbal system reemerged and became functional. The tactile information seemed to be represented in a manner that was impenetrable for linguistic analysis. These coexisting systems appeared to be insulated from one another, yet were present within the structure of the brain.

Implications for Psychiatry

The experiments with the split-brain and brain-damaged patients continue to elucidate the heterogeneous and autonomous behavioral functions of each hemisphere. Work over two decades has demonstrated that each hemisphere has an independent private complex of cognitive skills that can be mobilized for more than perceptual discriminations. Each hemisphere can autonomously generate opinions, judgments, attitudes, and emotions. Thus, these experiments support a model of interacting coconscious mental systems that directly study the interaction of cognitive processes which must be coordinated for a final behavioral act and which allow controlled observation of the distinctly human behavior of talking about those acts. The data suggest that a dynamic relation holds between nonverbal information processing systems, which can organize, represent, and retrieve information, and the more apparent verbal system. Our approach has been to examine the nature of this interaction in an attempt to gain insights into normal conscious mechanisms.

It should now be clear that by reporting on the interaction of the two hemispheres, we are not simply commenting on the intrinsic or isolated function of the left or the right hemisphere. Split-brain, or two-hemisphere, testing serves as a method for the examination of the interaction of verbal and nonverbal mental systems. Additionally, several of the split-brain testing techniques were modified for use in patients with focal neurologic defects. The experiments with patients who had suffered parietal lobe damage and those undergoing carotid amobarbital injection also demonstrate the interaction between verbal and nonverbal systems.

The recent split-brain experiments explore the extent to which an emotional response of a nonverbal system without access to the verbal system can influence complex behavior. For example, word selection for a simple declarative sentence might be biased by the mood state initiated by another nonverbal system. As a result of this intervention between mental systems, the statement might be at odds with previous attitudes about the point in question and could further lead the person to alter his previous belief about it.

During all of the experiments, the verbal system consistently attempted to incorporate experimentally induced overt behavior produced by nonverbal mental systems into a unifying understanding of personal motivation. For the patients, the language apparatus provided a means to attain a sense of unity. However, in view of the multiple coconscious mental systems that were demonstrated, this unity is an illusion. The ramifications of this notion has particular relevance for forensic psychiatry.

This work is not meant to suggest a specific neural substrate for the basic forces of the psyche as posited by the psychiatric literature. Nor is it meant to provide only a neural model that explains the therapeutic difficulties encountered in traditional psychoanalysis, where conscious experience is assessed exclusively by verbal output. The verbal mechanisms simply do not have access to all the nonverbal specific information systems that may exert crucial influence on behavior. The power and efficiency of verbal communication are not in question. The data do suggest that there are major deficiencies when the verbal system is used to evaluate the behavioral activities of coconscious mental systems.

Experiments with split-brain patients offer a model for behavioral disorders and an insight into the normal conscious mechanisms. A metaphor for the human condition of the duality of human nature, and the struggle with inner conflict, must be expanded to include multiple coconscious mental systems competing for access to the output mechanisms. The primary output mechanism— verbal behavior—may only infrequently have prior knowledge of behavior, as one or another coconscious nonverbal system controls the output mechanism. The language system may, at times, lag behind in organizing the conscious experience. This mental operation is only one of a number of operations, and the study of its interactions with nonverbal systems will continue to capture the imagination.

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Notes

1 Aided by U.S. Public Health Service Grant no. NS 15053, the McKnight Foundation, and the Alfred P. Sloan Foundation.