chapter 5

Brain and Consciousness I: Split-Brain Research

> Today, no one, psychologist, philosopher, neurologist, or humanist, is entitled to an opinion on the mind-body question if he is unfamiliar with the split-brain procedure and its results in human patients (Hebb 1974, p. 76).

The fundamental assumption of the materialist viewpoint on the mind-body problem is that mind and consciousness are functions of the brain. The ultimate promise of neuroscience is to explain how the brain produces the whole range of human mental processes: perception, memory, language, thinking, emotion, control of action, and last but not least, subjective consciousness. Cognitive neuroscience is still a long way from explaining mental processes in detail, but dramatic progress has been made in the last twenty years (see Ellis & Young 1988; Gazzaniga 1984). It is beyond the scope of this book to go into any detail on neuroscience research. However, in this chapter and the next I will discuss some neuropsychology research that is particularly relevant to the mind-body problem and questions of the nature of consciousness, including the question of conscious unity.

No neuropsychological research has caught the attention of psychologists, philosophers, and the general public so much as the "split-brain" research. It has stimulated hundreds of studies of hemispheric specialization in normal people as well as in split-brain patients (Springer & Deutsch 1985). It has led to speculations about the bimodal nature of consciousness (Ornstein 1977) and the possibility of dual-consciousness: two separate, independent centers of consciousness, one in each cerebral hemisphere. In 1981

Roger Sperry won the Nobel Prize for his pioneering research on the psychological effects of split-brain surgery.

As background to the discussion of neuropsychological research in this chapter and the next, I will begin this chapter with a brief description of the organization of the brain, for the benefit of readers who need a review of this topic. Then I will selectively review some of the split-brain research, beginning with a discussion of the rationale for split-brain surgery, and its typical effects on psychological test performance. Next I will take up the question of dual-consciousness. Then I will discuss split-brain evidence for specialized cognitive modules in the brain, which has implications for the nature of consciousness and the question of conscious unity. Finally, I will comment on the exaggerations and unjustified conclusions that some people have derived from split-brain research.

A BRIEF OVERVIEW OF BRAIN ORGANIZATION

In this section I will briefly describe the organization of the human nervous system and brain, emphasizing the cerebral cortex because it is particularly important for higher cognitive functions and consciousness in humans.

The nervous system is divided into two main parts: (1) The *central nervous system* (CNS), which includes the brain and the spinal cord. (2) The *peripheral nervous system*, which carries messages to and from the CNS. The peripheral nervous system includes: (a) The *somatic system*, which controls skeletal muscles and relays sensory messages about touch, pressure, pain, temperature, and muscle movement to the CNS. Also, the *cranial nerves* relay sensory messages (such as vision and hearing) and control muscle movements (such as speech) in the head and neck region. (b) The *autonomic system*, which controls the glands and energy organs such as the heart, blood vessels, lungs, and intestines. The autonomic system is divided into the *sympathetic* branch, which expends energy (as in emotional arousal), and the *parasympathetic* branch, which accumulates and conserves energy (as in relaxation and digestion).

The brain consists of three major divisions: the central core, the limbic system, and the cerebrum. The *central core* is the oldest part of the brain in evolutionary terms, being basically similar in humans, other mammals, and reptiles. Its parts include the brain stem (medulla and pons), cerebellum, thalamus, and hypothalamus. Figure 5.1 shows the location of these structures and their functions. In general, the central core controls basic body functions (such as heartbeat [medulla] and metabolism [hypothalamus]) and coordinated movements (such as walking [cerebellum]). The central core also includes the reticular system, which is a network of neurons that extends through the brainstem and thalamus, and is responsible for regulating the brain's level of arousal (as in the sleep-wakefulness cycle, and alertness to incoming stimuli).

The *limbic system* wraps around the central core and lies between it and the cerebrum. ("Limbic" means border.) Its main structures include the hippocampus, which is critical for memory storage and retrieval processes, and

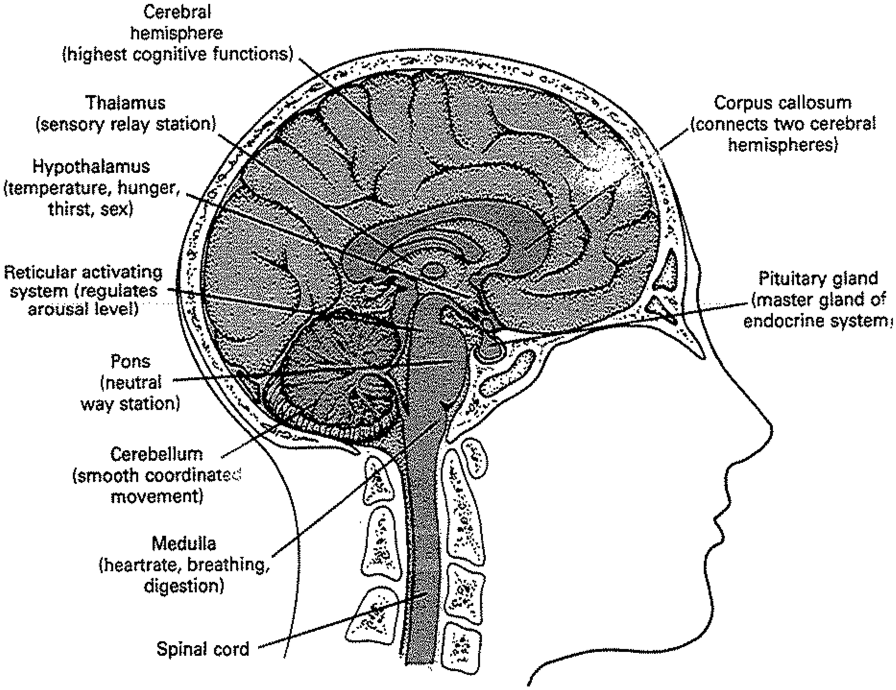

FIGURE 5.1. Cross section of the human brain, showing the locations of subcortical structures. [From Darley, J. M., Glucksberg, S., & Kinchla, R. A. (1991). *Psychology* (5th ed.). Englewood Cliffs, NJ: Prentice Hall. Adapted by permission of the publisher.]

the amygdala, which is important for both memory and emotional behavior (such as aggression).

The *cerebrum* is divided into two *cerebral hemispheres*, left and right, which are connected to each other via a bundle of neurons called the *corpus callosum*. The cerebrum's surface, the *cerebral cortex*, is responsible for higher mental functions. The cortex is about three millimeters thick, and consists of four to six layers of *neurons* (nerve cells) that interconnect both vertically and horizontally.[1]

The cerebral cortex. Figure 5.2 shows a left-side view of the cerebral cortex, including the four cortical lobes: frontal, temporal, occipital, and parietal. The cortex covers the brain somewhat like a football helmet covers a head. But the surface area of the cortex is much greater than that of a football helmet, because of the way the cortex is wrinkled and folded in on itself. The ridges of the cortex are called *gyri* (singular, gyrus), while the valleys in between the ridges are called *sulci* (singular, sulcus), and the deeper valleys that mark off the cortical lobes are called *fissures*.

Areas of the cortex are classified as primary sensory-motor areas or as association areas. *Primary sensory areas* do the first stages of analysis of incoming stimuli in the various sensory modalities. The primary sensory areas include the primary visual cortex (at the back of the occipital lobes), the primary auditory cortex (in the temporal lobes, mostly hidden from view inside

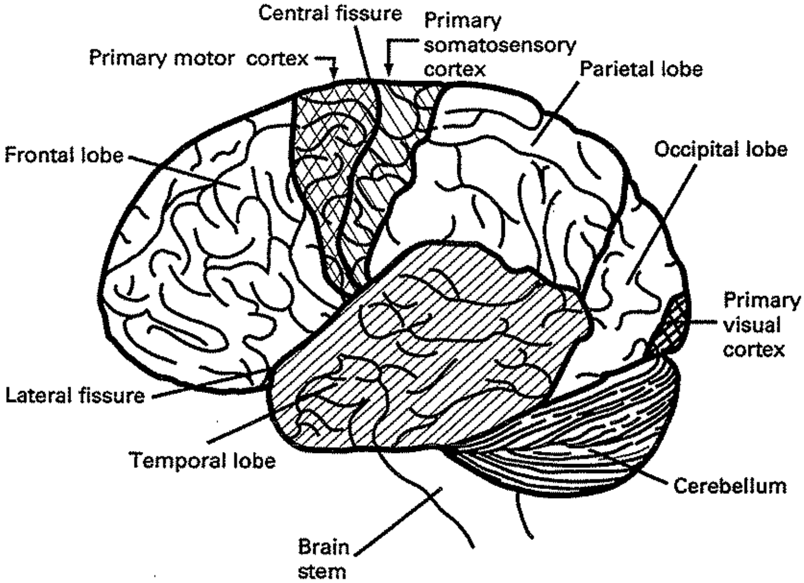

FIGURE 5.2. Side view of the cerebral cortex, showing the four lobes. Primary motor cortex is at the back of the frontal lobe; somatosensory cortex is at the front of the parietal lobe. The cerebellum is part of the central core.

the lateral fissure), and the primary somatosensory cortex, which feels the skin senses (touch, pressure, pain, temperature), and is located in the parietal lobes, just behind the central fissure. Damage to primary sensory areas can cause sensory losses. For example, damage to the primary visual cortex (striate cortex) can cause cortical blindness, even though the patient's eyes function normally. (In the next chapter I will discuss "blindsight," in which some cortically-blind patients can respond correctly to visual stimuli that they do not consciously see.) *Primary motor cortex* (in the frontal lobes, just in front of the central fissure) is responsible for controlling movements of the skeletal muscles to carry out actions programmed in the frontal lobes.

Cortical areas outside the primary sensory-motor areas are called *association cortex* because they associate stimuli from various modalities with each other, associate stimuli with memories and memories with each other, and generally carry out higher-level cognitive functions such as complex perception, thinking, memory, and control of actions.

Though the cerebral hemispheres look symmetrical, the left and right sides have different functions, particularly in the temporal and parietal lobes. Both *temporal lobes* are important for memory storage—particularly, episodic and semantic memory storage—working in conjunction with limbic system structures (hippocampus and amygdala). Bilateral (both sides) damage of the temporal lobes can cause *amnesia,* disruption of memory functions. The left temporal lobe is responsible for language understanding and production and it is slightly thicker than the right temporal lobe in humans. Damage to the left temporal lobe can cause various types of *aphasia,* disruptions of language functions. Because of the importance of language for thinking and communication, the left hemisphere is often called the *dominant hemisphere*.[2]

The *occipital lobes* process visual information, starting with elementary visual analysis in the primary visual cortex, and proceeding to more complex analysis and object perception in more anterior (forward) areas of the occipital lobes and adjacent areas of the parietal lobes. Damage to the occipital-parietal lobe area can cause *visual agnosia*, in which patients cannot recognize objects that they see.[3]

The *parietal lobes* are important for recognition of objects and for integration of information from different sensory modalities (for example, to compare what you are seeing with what you are touching). The left parietal lobe is especially important for naming objects, whereas the right is important for spatial perception functions, including the spatial relationships between objects, navigating in space, recognizing objects seen from unusual angles (such as a bucket seen from the top), and aiming movements. (Don't ever play darts with someone who has parietal lobe damage!) The left parietal lobe is important for short-term memory of verbal information, whereas the right is involved in short-term memory for nonverbal information (such as the locations of objects; see Kolb & Whishaw 1990).

The *frontal lobes* are critical for formulating plans for reaching goals, regulating the sequence of actions, inhibiting inappropriate responses, and programming specific sequences of coordinated movements. Damage to the frontal lobes can disrupt the ability to plan and carry out voluntary actions, and produce inflexible and perseverative behavior that fails to meet the requirements of the situation at hand. The frontal lobes, through their connections with the limbic system, are also important for regulating emotional behavior and aspects of personality organization (Kolb & Whishaw 1990; Luria 1973).

Contralateral organization. The cortex is organized according to the principle of contralateral organization, in which the left hemisphere analyzes stimuli and controls actions of the right side of the body, and the right hemisphere does the same for the left side of the body (see Figure 5.3). The left *somatosensory cortex* receives and analyzes skin sense and kinesthetic (muscle sense) information from the right side of the body; and vice versa. The left *motor cortex* controls voluntary movements of the right side of the body, such as the right hand and foot; and vice versa. A stroke, in which breaking or blocking of an artery on one side of the brain causes brain cells to die, usually causes partial paralysis on the contralateral side of the body.

Contralateral organization also applies to the senses of hearing and vision. The left primary auditory cortex has better neural connections with the right ear than with the left ear. Thus, the left hemisphere hears better from the right ear than the left ear; and vice versa. Contralateral organization for vision is more complex. The general principle is that the left occipital cortex sees the *right visual field* (RVF)—the area to the right of the *fixation point*—and the right occipital cortex sees the LVF. Figure 5.3 explains how this happens.

Normally sensory information and thoughts are shared between the

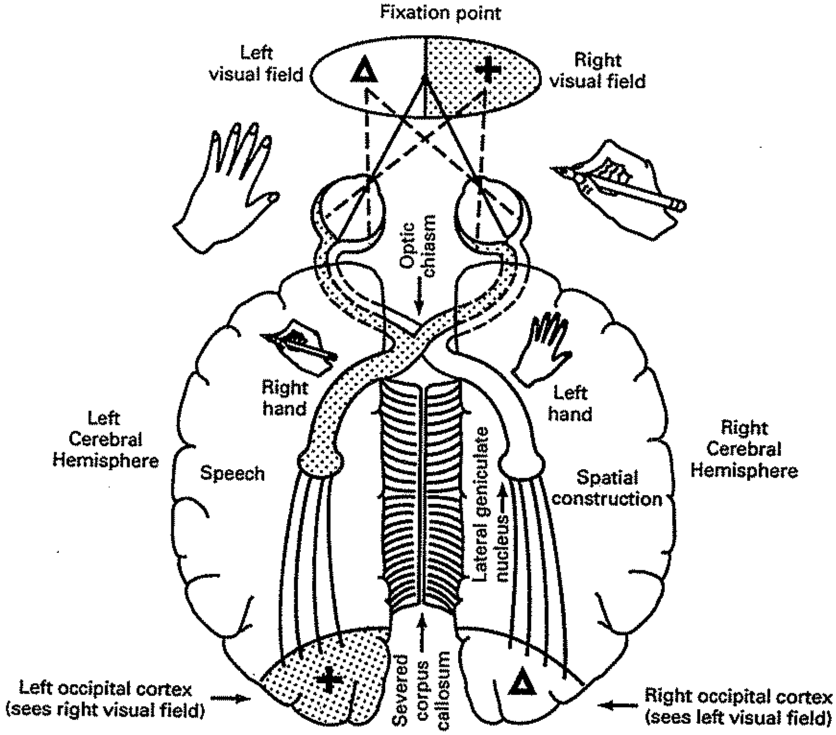

FIGURE 5.3. Sensory inputs to the two cerebral hemispheres in the split-brain patient. In accordance with the principle of *contralateral organization*, the left hemisphere controls movements and receives skin sensations from the right side of the body; and vice versa. The left hemisphere sees the right visual field (RVF) because light from the RVF falls on the left side of the retina of each eye, which connects to the primary visual area of the left occipital cortex via the optic nerves and the left lateral geniculate nucleus (a sensory relay station in the thalamus); and vice versa for the right hemisphere. [Adapted from Sperry, R. W. (1968). Hemisphere deconnection and unity in conscious awareness. *American Psychologist, 23,* 723–33. Copyright 1968 by the American Psychological Association. Adapted by permission.]

two hemispheres via the *corpus callosum*, the "great cerebral commissure." The corpus callosum is the largest fiber tract in the human brain, with over 200 million neurons. For the most part, the callosum connects *homotopic* or corresponding points between left and right frontal, parietal, and occipital lobes, and part of the temporal lobes, though there are also many instances where a point in one hemisphere connects to a point that is not exactly homotopic in the opposite hemisphere. A smaller left-right commissure, called the *anterior commissure* (not shown in Figure 5.3) connects portions of the anterior temporal lobes and also the *amygdala*, a limbic-system structure that plays roles in memory and emotional behavior. Any direct sensory input to one hemisphere can be transmitted almost immediately to the opposite hemisphere when both the corpus callosum and the anterior commissure are intact. But as we will see, when the commissures are cut, as in split-brain surgery, then sensory inputs and thoughts cannot be transmitted directly from one hemisphere to the other.

SPLIT-BRAIN RESEARCH

The effects of *commissurotomy*—surgical transection (cutting) of the corpus callosum—have been studied in both animal and human subjects. In the 1950s Roger Sperry and Ronald Myers did experimental research with cats and monkeys that proved that the corpus callosum is critical for communicating information between the left and right cerebral hemispheres (Sperry 1964). They showed, for example, that if a "split-brain" (commissurotomized) monkey's left hemisphere was trained on a visual discrimination task (choosing a triangle instead of a circle in order to get a food reward), then the right hemisphere did not know what the left hemisphere had learned.[4] Commissurotomy did not, however, have any harmful effects on the animal's functioning outside of the experimental testing situation.

The purpose of commissurotomy in human patients is to try to control severe epilepsy. In an epileptic seizure the normal complex patterning of brain activity is disrupted, and abnormal synchronous firing of neurons occurs over large areas of the cortex. Major seizures can be dangerous, since the victim can lose consciousness and motor control for several minutes. (Imagine what would happen if you had a major seizure while driving a car.) Seizures typically start in one hemisphere, and major seizures can spread rapidly to the opposite hemisphere. Thus, it was reasoned that if seizures could be confined to one hemisphere by cutting the corpus callosum, then their effects would not be so dangerous to the patient.

The first commissurotomies on human patients were done in the 1940s. Unfortunately, in most patients the procedure was not as effective in controlling epilepsy as had been hoped, so the procedure was temporarily abandoned. About twenty years later, two California neurosurgeons, Philip Vogel and Joseph Bogen, reconsidered the question of commissurotomy and epilepsy. They examined earlier surgical records and more recent animal and human research, and concluded that commissurotomy had failed to help control epilepsy in most of the 1940s patients because in most cases only a partial commissurotomy had been done. Vogel and Bogen hypothesized that a complete transection of both the corpus callosum and the anterior commissure would prevent the conduction of epileptic seizures between the two hemispheres. Their first full commissurotomies were a complete success. The patients' seizures were controlled as predicted. And commissurotomy produced no harmful effects as far as the patients' daily lives were concerned. They could go about their work and play and interact with family and friends as well as before—or better, because of the reduced epilepsy problem.

However, extensive testing by neuropsychologists Roger Sperry and Michael Gazzaniga subsequently showed a number of subtle but profoundly important psychological effects of the split-brain procedure in human subjects. I will describe some of the prototypical results from the "California series" of some two dozen split-brain patients. However, before I describe the split-brain research some preliminary comments and cautions are in order.

Preliminary comments. The advantage of testing split-brain subjects is that it enables researchers to study a hemisphere's functioning directly, by seeing what the intact hemisphere *can* do, rather than relying on studies of dysfunctions resulting from damage to the hemisphere. Yet split-brain test results must be interpreted with caution for several reasons: (1) The brains of the split-brain patients are not entirely normal, since these patients were afflicted with severe epilepsy. Thus, results from split-brain research cannot always be generalized to normal brains. (2) The number of split-brain subjects is relatively small, and it is risky to draw big conclusions from a small sample. (3) To make matters worse, the split-brain subjects show considerable variability among themselves. The prototypical results that I am summarizing here do not necessarily apply to all of the split-brain subjects. The differences between subjects are due mainly to differences in the amount and location of damage to one or the other hemisphere prior to the split-brain surgery. For example, in some patients the right hemisphere is relatively unresponsive. The results that I describe come from patients with responsive right hemispheres. (4) When one hemisphere is damaged, the other hemisphere may be able to acquire some of its functions. Thus a certain amount of functional reorganization of the brains of some patients may have occurred prior to surgery. For example, the surprising degree of right-hemisphere speech-recognition ability in some split-brain patients may reflect an abnormal acquisition of language by the right hemisphere as a result of left-hemisphere damage from epilepsy. (5) Also, if each hemisphere can learn independently, then after the surgery each hemisphere might acquire some functions that it did not have prior to surgery. Thus, some of the split-brain research may show what the separated right and left hemispheres are capable of learning to do, rather than what the connected hemispheres normally do in normal brains. This presents a problem in interpreting some studies that were done months or years after the surgery. With these caveats in mind, let us consider some of the research with split-brain patients. The results are fascinating and they have raised some important new questions.

Neuropsychological Testing

To understand the rationale behind the test procedures it is important to bear in mind the principle of *contralateral organization* of the sensory and motor systems (Figure 5.3). In the fully commissurotomized patient the left hemisphere sees only the right visual field, and vice versa. However, under ordinary viewing conditions the patient, by moving his or her eyes, can see an entire scene with each of the two hemispheres. Thus, in order to test each of the two hemispheres independently (unilateral testing) it was necessary to limit stimulus inputs to a single hemisphere. Several methods were devised for doing this. (In what follows I will simplify things by describing the procedure and results for typical right-handed patients, in whom language production mechanisms are in the left hemisphere.)

The simplest method of unilateral testing involved asking subjects to identify objects (such as spoon, key, pencil) by touch alone. The objects were out of sight, inside of a box. Subjects stuck a hand through a hole in the side of the box to feel the objects. When the right hand was used, the subjects could name the object, just like normal people. But when the left hand was used, they could not name it. Thus, the left hemisphere knew what object the right hand had felt, and named it accurately. But the right hemisphere could not name what the left hand had felt. However, the fact that the right hemisphere *knew* what the left hand had felt was shown by the fact that it could show how to use it: for example, while blindfolded, subjects could use the left hand to show how to use a spoon or a paintbrush, using appropriate motions.

You might wonder how the experimenter explained to a subject's nonspeaking right hemisphere what it was supposed to do in the left-hand tests. Verbal instructions were sufficient for some patients, since their right hemisphere had some degree of speech recognition ability, though it could not produce speech. In other cases it was necessary to demonstrate the testing procedure, and the right hemisphere learned by observing.

In order to test the left and right hemispheres separately for recognition of visual stimuli, a projection tachistoscope ("T-scope") was used to *lateralize* the visual stimuli (Figure 5.4). Subjects focused on a dot at the center of the screen, then a visual stimulus—a picture or a word—was flashed on either the right or left side of the screen. The flash was so brief—about 150 milliseconds—that the subjects did not have time to move their eyes during the flash. Thus, for example, if a picture was flashed on the left side of the screen (in the left visual field, LVF), only the right hemisphere could see it, since the subjects could not move their eyes leftward quickly enough to see the picture on the left side of the screen in the right visual field (RVF), with the left hemisphere.

In a typical T-scope test, the subjects were told to name whatever object was shown in a picture flashed on the screen. If the picture was flashed in the RVF, subjects correctly named it. But if the picture was flashed in the LVF, they could not name it. In fact, they usually said that they saw "nothing." Yet, if they were asked to reach through an opening under the screen and feel several objects (such as a spoon, pencil, key, cigarette, and clothespin) with their left hand (without being able to see the objects) then they could select the object that *matched* the one seen in the LVF (*cross-modal matching procedure*). Again, the left hemisphere can name what it sees; the right hemisphere knows what it sees, but cannot name it (Gazzaniga 1970). Interestingly, the same results were obtained in some subjects when the stimulus was the printed name of the object ("SPOON"), rather than a picture of it. The right hemisphere could read common nouns, and select the corresponding object by touch, but it could not speak to read the words aloud.

Another test showed that the right hemisphere could understand concrete concepts. An object was flashed in the LVF, and the subject's task was to use the left hand to select by feel the object that "goes with" the object that he saw (while the identical matching object itself was not available). For example, if the subject saw a cigarette, his or her left hand selected a cigarette lighter. Thus, the right hemisphere understood concrete concepts having to do with functional or category relations between the objects.

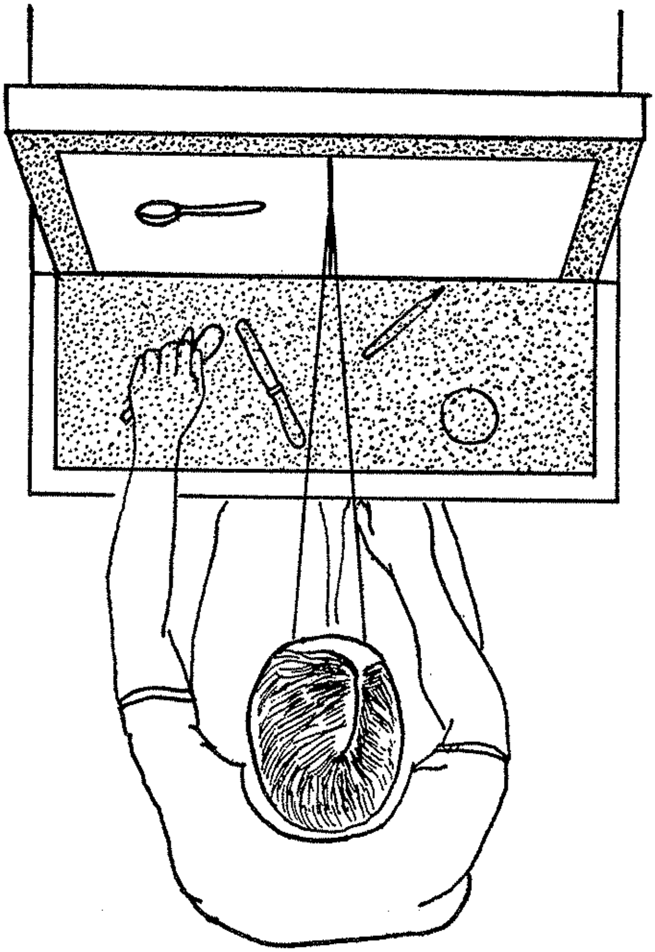

FIGURE 5.4. Apparatus for testing visual-tactile association in split-brain patients. Here the right hemisphere sees the picture projected in the left visual field; the left hand picks the matching object from among several objects that are out of sight on a shelf under the table. [From Gazzaniga, M. S. (1970). *The Bisected Brain.* New York: Appleton-Century-Crofts. By permission of Appleton & Lange.]

A more complex sort of recognition was demonstrated when, in the middle of a routine visual-recognition and naming test, a picture of a nude female was flashed to the LVF of a female subject. She giggled and blushed, as if embarrassed. When asked what she had seen, she said "Nothing, just a flash of light." When asked why she had laughed, she replied "Oh Dr. Sperry, that's some machine you have!" This example shows that the right hemisphere not only recognized the picture, but initiated an automatic emotional reaction to it—one based on the patient's social learning experience. The speaking left hemisphere did not know what had been seen, but it tried to interpret the emotional reaction, as shown by the remark about "some machine." (Later, I will have more to say about the significance of the left hemisphere's attempt to interpret the right hemisphere's actions.)

Visuospatial superiority of the right hemisphere. Numerous studies of split-brain patients have indicated that the left hemisphere is superior to the right for verbal and conceptual tasks, whereas the right hemisphere is superior for many nonverbal tasks, particularly visuo-spatial tasks involving drawing and construction (Gazzaniga & LeDoux 1978). For example, in the *block-design test* the subject is required to use a set of colored blocks (cubes with a different color of paint on each side) to construct a pattern that matches a sample pattern shown in a picture. The sample pattern remains in full view during the construction test. Split-brain subjects can construct the correct block pattern quickly and easily using their left hand (right hemisphere), but they find the task difficult or impossible with their right hand (left hemisphere).

Figure 5.5 illustrates the right hemisphere's (left hand) superiority in drawing, in right-handed split-brain patients. Gazzaniga and LeDoux (1978; Gazzaniga 1985) argued that the right hemisphere's superiority in spatial tasks is limited to tasks that require some sort of manipulation of objects in space, construction of figures, or tactile recognition of shapes. On tests involving mere matching of figures and pictures, in which a simple pointing response is used, the left hemisphere usually performs as well as the right hemisphere. Thus, Gazzaniga and Ledoux argued for *manipulo-spatial* superiority of the right hemisphere, rather than a general visuo-spatial superiority.

Face recognition. The right hemisphere is better than the left at recognizing faces. This was demonstrated in a study by Levy, Trevarthen, and Sperry (1972) that used composite pictures, with the left half from one face and the right half from a different face (see Figure 5.6). Such composite figures are called *chimeric figures* (after Chimera, an ancient mythical monster whose various parts [head, body, forelegs, and so forth] came from different animals). The chimeric face was flashed briefly on the T-scope screen, then the subject had to choose the face that she had seen from among a set of four faces. If subjects responded by pointing, the responses were controlled by the right hemisphere, and they were nearly always correct. The fact that the responses were controlled by the right hemisphere was known by the fact that subjects chose faces that matched the left half of the chimeric face stimuli.[5]

When subjects were required to respond verbally rather than by pointing, they usually chose faces that matched the right half of the chimeric face, indicating control by the left hemisphere. Face-matching performance was better for right-hemisphere control than for left-hemisphere control, though the left hemisphere still matched at better than a chance level. (Another experiment showed similar results with chimeric stimuli made of common objects, such as a rose, eye, or bee.) Gazzaniga and LeDoux (1978; Gazzaniga 1985) found that the right hemisphere's superiority at face recognition was limited to tests involving similar faces, in which it was hard to discriminate

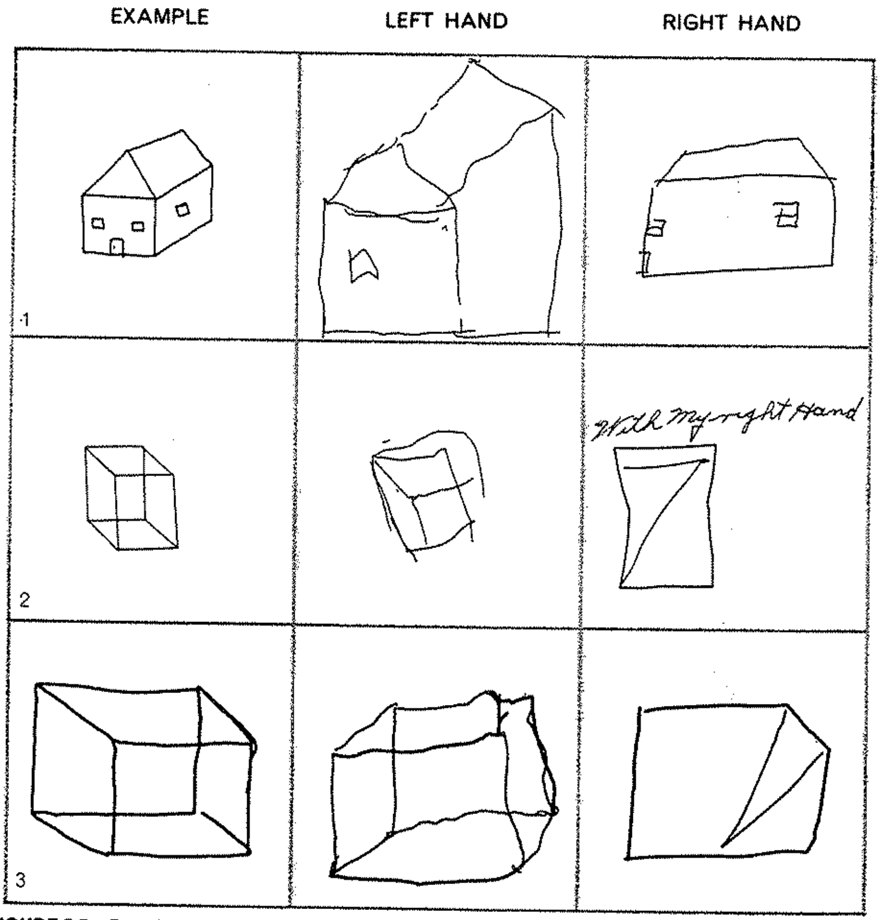

FIGURE 5.5. Drawings by three split-brain patients. After commissurotomy, these right-handed patients could copy designs better with their left hand (right hemisphere) than with their right hand. Conversely, only their right hand (left hemisphere) could write words spontaneously (without copying). [From Gazzaniga, M. S. (August, 1967). The split brain in man. *Scientific American, 217*, 24–29. By permission of the author.]

between the different faces. The left hemisphere did a good job when the faces were distinctively different. This latter finding illustrates an example of a general principle that, in many cases, differences between left hemisphere and right hemisphere abilities are relative, not absolute.

One rather striking finding in the studies using chimeric stimuli was the phenomenon of *visual completion*, in which patients subjectively perceived figures as complete when in fact they had seen only half of the figure (in either the LVF or RVF). For example, in the chimeric face study, the patients perceived unified whole faces, not half faces or chimeric faces. This phenomenon is not understood, but it seems to be a complex case of the Gestalt perception principles of good continuation and closure. (Visual

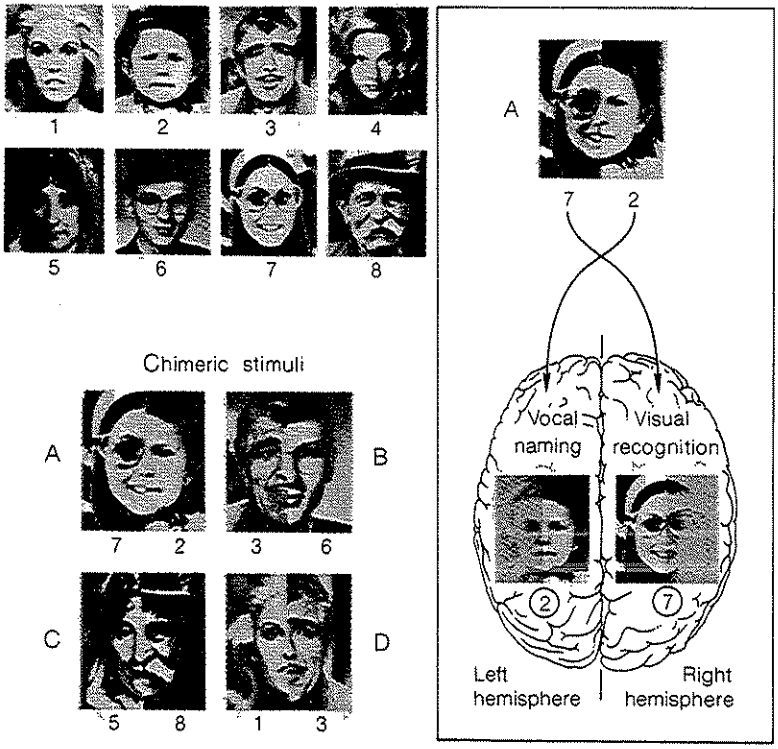

FIGURE 5.6. Stimuli used in face recognition experiment by Levy et al. First the subject saw a chimeric stimulus (A, B, C, or D) flashed on the screen, then he was asked to point to the face that he had seen, choosing from pictures 1–8. When they responded by pointing, subjects typically chose the whole face that matched the left side of the chimeric face (seen in the right hemisphere); for example, chimeric face A was matched to picture 7. But when they responded verbally, they chose a whole face that matched the right side of the chimeric face (seen in the left hemisphere); for example, chimeric face A was matched to picture 2. [From Levy, J., Trevarthen, C., & Sperry, R. W. (1972). Perception of bilateral chimeric figures following hemispheric disconnection. *Brain, 95,* 61–78. By permission of Oxford University Press.]

completion is greatest soon after surgery; over a period of time it may decrease, and the patient will notice that his or her visual field is incomplete.)

Other left-right differences. Besides visuo-spatial or manipulo-spatial superiority, other superiorities of the right hemisphere on nonverbal tasks have been claimed, with varying degrees of evidence. For example, it has been suggested that the right hemisphere is superior to the left in recognizing musical melodies. Special techniques have been devised to study hemispheric differences in normal subjects, with normal brains. This research is beyond the scope and purpose of this book, but see Springer and Deutsch (1985) for a good review of the research on hemispheric differences in normal and abnormal brains in adults, children, and animals.

Hemispheric dominance and specialized abilities. The left hemisphere has traditionally been called the *dominant* hemisphere since it controls speech and since verbal thought seems to be so important for the control of voluntary action. However, the split-brain research shows that under appropriate conditions the right hemisphere can take charge and perform tasks that suit its talents (such as the face-recognition and block-designs tasks). Levy and Trevarthen (1976) used chimeric object pictures to show that the left hemisphere usually controls responding in a function-matching task (matching objects that are used together, such as a fork and a birthday cake), but the right hemisphere usually controls responding when the task requires matching of objects according to their visual similarity.

It appears that each hemisphere is capable of thinking independently, insofar as thinking is required for correct performance on the various tasks used by neuropsychologists to test the split-brain patients. This raises the question, do split-brain patients have two minds? And especially important, do they have two separate centers of consciousness, one in each hemisphere? We will consider this fascinating question in the next section.

THE QUESTION OF DUAL CONSCIOUSNESS

The question of interest here is whether the split-brain operation, involving complete commissurotomy, produces two centers of consciousness within one body. That is, can it be said that the separated left and right hemispheres are independently conscious just as one would say that two different brains in two different bodies are independently conscious? The main controversy has been over whether the separated right hemisphere is conscious. The speaking left hemisphere seems to function in a normal manner, making introspective verbal reports in casual conversation, so there has not been any serious doubt that the separated left hemisphere is conscious.

The question of dual consciousness is highly controversial among psychologists, philosophers, and brain scientists (Beaumont 1981; Globus, Maxwell, & Savodnik 1976). The two most important reasons for disagreement on this issue are: (1) failure to agree on an objective criterion for consciousness, and (2) limitations of the empirical evidence. The conclusions that different writers have drawn from the available evidence seem to depend heavily on their prior philosophical or theoretical beliefs about consciousness and the brain.

The Problem

The question of whether a split-brain patient's mute right hemisphere is a conscious being is a special case of the *other-minds problem*, which I discussed in the previous chapter. The speaking left hemisphere has no direct knowledge of the right hemisphere's experience. It can only make inferences based on emotional reactions and behavior initiated by the right hemisphere. Thus, to the split-brain patient's left hemisphere, the right hemisphere is an "other mind." However, in ordinary day-to-day life the patients are not concerned with this other mind. They do not say "I feel like my consciousness is split" or "I think that I have two minds." Except for occasional "alien hand" episodes, in which the left hand does something suggesting independent volition, the right hemisphere is so unobtrusive that the possibility of a second center of consciousness does not occur to the split-brain patients. It is mainly psychologists and philosophers and brain scientists who are interested in the question.

Taking the objective viewpoint, we must approach the question of right hemisphere consciousness in the same way that we would approach the other-minds problems in regard to animals or pre-verbal children. We must develop some objective criterion with which to infer consciousness. The criterion that we choose will be influenced by our ideas about what consciousness is, and the level of consciousness with which we are concerned.

In the most conservative view, linguistic thought is an essential feature of consciousness, and the introspective verbal report (IVR) is a necessary criterion for consciousness (or at least for self-awareness; Beaumont 1981). The IVR criterion was advocated by John Eccles (1977), an interactionist dualist who claimed that the left hemisphere (particularly the prefrontal lobe and the linguistic circuits of the temporal lobe) is a "liaison cortex" that transmits knowledge from an immaterial entity, the "self-conscious mind," which has subjective conscious experiences. Thus, in Eccles's view, language centers do not produce consciousness, rather, they receive knowledge from an immaterial consciousness, and can make introspective verbal reports about it. Though Eccles himself is an eminent brain scientist, his theory of "liaison cortex" has not been accepted by very many other brain scientists. Brain scientists taking a strictly materialist view (such as Gazzaniga 1985, 1988), have argued that higher-level conscious processes (above mere sensory perception) are highly correlated with the presence of linguistic circuits normally found only in the left hemisphere, and IVR is the most useful indicator of consciousness, though not necessarily the only one.

Roger Sperry (1968, 1976) took a more liberal attitude toward the possibility of consciousness occurring in the right hemisphere, independent of language circuits and introspective verbal reports:

> 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.") (1966, p. 299).

Sperry conceived of subjective consciousness broadly, covering the whole range from perceptual awareness to self-awareness. He did not see linguistic thinking as an essential feature of consciousness, nor did he require introspective verbal reports as an objective criterion for subjective consciousness. Rather, he took *intelligent behavior*—behavior adaptive to the current situation and controlled by flexible thought processes rather than reflexes—as sufficient evidence from which to infer consciousness. Sperry's attitude on a criterion for consciousness is consistent with his emergent interactionism theory (discussed in Chapter 4), in which consciousness is identified with the holistic properties of neural activity and plays a causal role in controlling behavior. While consciousness is unified via the corpus callosum in the normal brain, the split-brain operation creates separate centers of consciousness in the two hemispheres, since their holistic neural activities are now separate.

The notion of intelligent action as a criterion for consciousness also makes sense from an identity-theory viewpoint on the mind-body problem. In any case, recall that both solutions to the other-minds problem—the IVR and the intelligent action criteria—depend ultimately on an argument from analogy. We attribute consciousness to creatures that we see as being similar to ourselves. The argument is over which criterion of similarity to use.

The Evidence

Here I will describe several lines of evidence for conscious thinking in the right hemisphere, according to the criterion of intelligent behavior.

Cognitive tasks. We have already seen that both the left and right hemispheres of split-brain patients are capable of intelligent action, though they have different talents. In normal adult humans, conscious thinking is highly correlated with intelligent behavior and presumably plays some role in producing it. Though intelligent action is usually related to conscious verbal thinking—a function of the left hemisphere—it can also follow from thinking in visual-spatial mental images, which is a special talent of the right hemisphere.

To give another example (Gazzaniga 1985): A picture of a horse was flashed to patient JW's right hemisphere (LVF). The left hemisphere said it did not see anything. But in response to the experimenter's request to "draw what goes on it," JW's left hand drew a picture of an English saddle. The drawing was ambiguous, and JW (left hemisphere) said he did not know what he had drawn. Then in response to the experimenter's request to "draw what you saw," the left hand drew a horse. JW then grinned and, pointing to the first drawing, said "That must be a saddle." Again, the right hemisphere followed instructions and carried out the task, operating independently of the left hemisphere. Thus, it appears that intelligent behavior of the disconnected right hemisphere is influenced by conscious, though nonverbal, thinking in that hemisphere.[6] The alternative interpretation would be that the right hemisphere is an automaton that conducts intelligent behavior in a non-conscious, computer-like manner. Those who claim that verbal thinking is of the essence of consciousness would classify the right hemisphere as a non-conscious entity as a matter of a prior definition.

To argue that the right hemisphere controls intelligent behavior is not to say that the right hemisphere is as smart as the left hemisphere. LeDoux

(1985) suggested that, "In the absence of extensive linguistic representation, the cognitive capacities of the right hemisphere are more like those of a chimpanzee than like those of a fully developed human" (p. 208). LeDoux, like Gazzaniga, argued that only the left hemisphere is conscious in the typical split-brain patient. However, I would argue that chimpanzees are conscious beings (Griffin 1984), so equating the human right hemisphere with a chimpanzee does not support the argument that the right hemisphere is not conscious.

Volition and the alien hand. Most of the time split-brain patients go about their daily lives without any apparent conflict between their two brain hemispheres. The right hemisphere either cooperates with the dominant left hemisphere, helping where it can, or else it remains passive and does not interfere. Laboratory studies show that the right hemisphere can follow instructions, making responses that suit the demands of the task at hand, within the limits of its talents. But can the right hemisphere initiate voluntary actions on its own initiative, independently of instructions from an experimenter or from its left-hemisphere companion? Evidence for spontaneous, presumably voluntary action by the left hand would support the hypothesis of independent consciousness in the right hemisphere of split-brain patients. Unfortunately, there is no systematic research evidence on this point. However, a few compelling incidents have been reported.

Gazzaniga (1970) described conflicts between the left and right hemispheres of his "Case I," a forty-eight-year-old war veteran:

> [He] would sometimes find himself pulling his pants down with one hand and pulling them up with the other. Once, he grabbed his wife with his left hand and shook her violently, while with the right trying to come to his wife's aid in bringing the belligerent hand under control (p. 107).

In another incident a patient's left hand slammed a drawer on his right hand, when his right hand reached into the drawer to get a pair of socks.

A French neurologist labeled such independent actions of the left hand as "la main étrangère," the *alien hand.* Some of the alien hand incidents seem to show conflict between the left and right hemispheres.

A dramatic instance of independent action by the left hand was caught on film (Gazzaniga 1970, p. 100; 1975 [film]). Case I was being tested on the blocks-design task, which involves arranging a set of colored blocks to match a printed pattern. The left hand (right hemisphere) constructed the pattern easily. The right hand (left hemisphere) was incompetent at the task, repeatedly making false starts. Then suddenly, while the right hand was fumbling with the blocks, the left hand reached out for the blocks and started to construct the pattern. This happened several times. It was necessary to ask the subject to sit on his left hand, to keep it out of the way so the right hand could be tested. Even while being sat upon, the left hand sometimes seemed to be trying to get loose. (It should be pointed out that Case I was unusual in that he never acquired ipsilateral control of the hands. Most split-brain patients develop ipsilateral control within a few months after surgery, so that the right hemisphere can control the right hand in doing the blocks design test.)

Cross-cueing. Several cases of cross-cueing between the hemispheres have been reported, in which, for example, the left hemisphere is able to guess what the right hemisphere has seen or felt by noticing the right hemisphere's overt responses to the situation (Gazzaniga 1970). I have already mentioned the case of the woman who blushed and giggled when her right hemisphere saw a slide of a nude. The left hemisphere did not know what the right hemisphere had seen, but correctly guessed that it was something unusual or funny. This is a case of inadvertent cross-cueing, with the left hemisphere interpreting responses that were made spontaneously but unintentionally by the right hemisphere.

Another example: A subject was being tested for his ability to name color patches that were flashed to either the left or right visual field. When the right hemisphere saw the flash (in the LVF), the left hemisphere could not name the color. But performance improved when the subject (that is, the speaking left hemisphere) was allowed to make a second guess. For example, after a red flash he guessed "green," then changed his answer to "red." The experimenter noticed that after the incorrect first guess the subject frowned and shook his head, then changed his answer. Apparently the right hemisphere heard the first response and realized that it was wrong. Its response (frown and head shake) was noticed by the left hemisphere, which then changed its answer. In this example it is not clear whether the right hemisphere's reaction to the error was a spontaneous emotional reaction or a deliberate cue to the left hemisphere; maybe it was spontaneous at first, and later became a deliberate cue.

Some cases of cross-cueing look strongly like deliberate attempts of the right hemisphere to send information to the left hemisphere via overt responses. For example, in a test in which only the right hemisphere could see pictures of familiar people, and the left hemisphere tried to guess who was in the pictures, one subject's left hand traced letters on the back of the right hand. When the right hemisphere saw the subject's aunt Elizabeth, the left hand traced an "E" on the back of the right hand, then the patient (left hemisphere) said "Elizabeth!" (Sperry, Zaidel, & Zaidel 1979).

It must be pointed out that incidents suggesting independent action by the right hemisphere/left hand are relatively rare. Furthermore, there is no evidence that the right hemisphere independently sets long-term goals and plans a series of actions to meet those goals. The available evidence suggests, at best, independent right-hemisphere action that is either impulsive or in pursuit of short-term goals in response to the demands of the immediate situation. Ordinarily the patients' voluntary actions seem to be controlled by the speaking left hemisphere, and the right hemisphere either actively cooperates or quietly acquiesces with the left hemisphere's dominance. It is not clear how one could detect long-term goal setting and planning by the right hemisphere, independent of the left. But there is no reason to expect the right hemisphere to have goals that conflict with those of the left hemisphere—after all, the two hemispheres have "lived together" for many years, and they are parts of the same person, in the same body. Nonetheless, the evidence for at least short-term voluntary action by the right hemisphere is strong enough to suggest that the right hemisphere is conscious, independently of the left hemisphere.

Self-recognition and social values. The evidence from cognitive tests suggests that the right hemisphere of split-brain patients has perceptual consciousness and conscious thinking. But what about self-awareness? It is difficult to test the mute right hemisphere for the full range of self-knowledge and self concept that is implied by the concept of self-awareness, and little research has been done on this topic. However, Sperry, Zaidel, and Zaidel (1979) devised an ingenious way for testing self-recognition, the most elementary aspect of self-awareness. They also studied the right hemisphere's sense of values or social awareness, to determine whether it was similar to what one would expect in a normal conscious, socialized human being.

Sperry et al. used a special contact lens, the "Z lens," that was designed to limit the subject's vision to the left visual field (right hemisphere). Subjects could examine photographs for an unlimited amount of time and shift their focus from one part of the picture to another. Thus, the experimental procedure could be much more flexible than it was with the T-scope apparatus used in earlier studies, in which stimuli were briefly flashed to one visual field or the other.

The subjects were two split-brain patients who had been operated on eight to ten years previously. They viewed a series of fifty stimulus cards, each of which had an array of four to nine drawings or photographs. Ten of the cards contained pictures of personal significance to the subject, such as pictures of the subject himself/herself, friends, relatives, or personal belongings. Other cards included famous people. For each card the subjects were instructed to point to one of the items that they recognized, or would like to have, or would use in a specified situation. They were asked to evaluate the chosen item with a "thumbs-up" or "thumbs-down" signal.

The results are so interesting that it is worth quoting some of the test protocols for the right hemisphere in detail. Here is one for subject NG, a married woman with two children. Keep in mind the fact that the experimenter is conversing with the subject's *left* hemisphere, which does not know what the right hemisphere is seeing in the pictures.

> *Protocol NG.* The subject had just completed six trials on comparatively neutral stimuli including foods, flowers, animals, children, and people with questions centered around her special preferences, likes and dislikes, the responses to which had been relatively casual and routine. On the seventh trial we presented four portrait head and bust photos in black and white, all of the subject herself in different poses along with the impersonal instruction: "Here are four people; again, point out the one you like best."
>
> NG: "OK," and she paused silently for about seven seconds while she examined the test array. She then burst forth with an abrupt loud exclamation: "Oh no! . . . Where'd you g . . . What *are* they?" This was followed by a very loud laugh, another exclamation, "Oh God!", and a three-second pause. She then asked hesitantly, "Dr. Sperry . . . You sure there's people there?"
>
> Ex: "Which one do you like . . . that one?" (referring to the one where the subject was pointing).
>
> NG: "Uh-huh."
>
> Ex: On removal of the choice array the examiner asked, "What was in the picture?"

NG: Still in an extra loud, emphatic voice, "Something nice whatever it was . . . Something I wouldn't mind having probably." This was followed closely by another loud laugh. (Sperry et al. 1979, p. 158. Copyright 1979 by Pergamon Press, Inc. Reprinted by permission.)

The experimenters interpreted the subject's loud emotional outburst at the unexpected sight of a picture of herself as strong evidence of self-recognition in the right hemisphere. They suggested that "the emotional components of the reaction triggered in the right hemisphere crossed rapidly to the left hemisphere through brain stem mechanisms and colored the tone of speech in the vocal hemisphere," though the left hemisphere did not know what the right hemisphere had seen that had triggered the emotional response. The subject's initial exclamation "Oh no! Where'd you g . . ." and "Oh God!" may have come from the right hemisphere, which may be capable of emotional vocal reactions, though it does not control conversational speech.

On a later test with a similar array of four pictures of herself, NG made a correct verbal identification. First she guessed "Probably me . . . ," then she said in a more definite tone, "Yeah, that's a picture of me." Apparently the right hemisphere heard and affirmed the left hemisphere's guess; the left hemisphere detected the affirmation and then made a positive identification of the picture.

Here are two protocols from a male subject, LB. His right hemisphere made blatant, overt attempts to cue the left hemisphere by using the left hand to trace letters on the back of the right hand.

Protocol LB.1. The subject was shown an array of four pictures of people, singly and in groups. Three of the pictures contained unknowns and one in the upper left included a picture of Hitler in uniform standing with four other men. LB was asked to point to "any of these that you recognize."

LB: examined the card for about fourteen seconds and then pointed to the face of Hitler.

Ex: "Do you recognize that one? Is that the only one?"

LB: again inspected the full array but did not point to any others.

Ex: "Well, on this: is this one a 'thumbs-up' or a 'thumbs-down' item for you?"

LB: signaled "thumbs down."

Ex: "That's another 'thumbs-down'?"

LB: "Guess I'm antisocial." (Because this was his third consecutive "thumbs-down.")

Ex: "Who is it?"

LB: "GI came to mind. I mean . . ." (Subject at this point was seen to be tracing letters with the first finger of the left hand on the back of his right hand.)

Ex: "You're writing with your left hand; let's keep the cues out."

LB: "Sorry about that."

Ex: "Is it someone you know personally, . . . or from entertainment, . . . or historical, or . . . ?"

LB: interrupted and said "Historical."

Ex: "Recent or . . . ?"

LB: "Past."

Ex: "This country or another country?"

LB: "Uh-huh—okay."

Ex: "You're not sure?"

LB: "Another country, I think."

Ex: "Prime Minister, king, president, . . . , any of them?"

LB: "Gee," and pondered with accompanying lip movements for several seconds.

Ex: Giving further cues: "Great Britain? . . . Germany . . . ?"

LB: interrupted and said definitely "Germany" and then after a slight pause added "Hitler" (Sperry et al. 1979, pp. 159–60).

Here LB's right hemisphere promptly recognized Hitler, and a negative emotional reaction prompted the "thumbs down" signal. The right hemisphere's subtle reactions to the experimenter's prompts cued the left hemisphere to guess "governmental" and "historical," while rejecting other alternatives. The right hemisphere, which could spell but not speak, tried to signal "Germany" to the left hemisphere by tracing letters with the left hand. Finally, recognizing the right hemisphere's affirmative reaction to the experimenter's "Germany" prompt, the left hemisphere confidently and correctly guessed that the picture was Hitler. Only Hitler could have produced such a strong negative reaction consistent with "governmental," "historical," and "Germany."

Protocol LB.2. In the preceding trials with the left visual field LB had responded with "thumbs-down" evaluations for Castro, Hitler, overweight women in swim suits, and a war scene. Intermixed with these and other responses, "thumbs-up" signals were obtained for Churchill, Johnny Carson, pretty girls, scenes from ballet and modern dance, and a horizontal neutral thumb signal for [then President] Nixon. Toward the end of this testing session, LB was presented with a choice array containing four portrait photos of adult males, three strangers, and one of himself in the lower left position. Asked for a thumb sign evaluation, he gave a decisive "thumbs-down" response but unlike other "thumbs-down" signals, this one was accompanied by a wide, sheepish and (to all appearances) a self-conscious grin. When we then asked if he knew who it was, LB after only a short hesitation guessed correctly "myself" (Sperry et al. 1979, p. 163).

Here LB's right hemisphere readily recognized his own portrait. The "thumbs down" signal combined with the wide grin "indicates not only self-recognition in the minor hemisphere but also a subtle sense of humor and self-conscious perspective befitting the total situation." The distinctive emotional reaction and other cues enabled the left hemisphere to identify the picture correctly as the subject himself.

Sperry et al.'s (1979) study indicates self-recognition in the right hemisphere of patients NG and LB, and self-recognition is the minimum criterion for self-awareness and a self-concept. The emotional reactions and thumb signals indicate an appropriate sense of social values in the right hemisphere, which suggests a self that holds those values. Independent volition by

LB's right hemisphere was shown by its attempts to signal the left hemisphere by tracing letters with the left hand.

Conclusions. Research by Sperry and his colleagues supports the notion of dual consciousness in split-brain patients (at least in those whose right hemisphere is not badly damaged). The right hemisphere shows perceptual awareness and conscious thinking by the criterion of a pattern of intelligent behavior (adaptive, purposive [at least in the short-term], flexible and spontaneous). Only by the narrow criterion of introspective verbal report could right-hemisphere consciousness be denied. The evidence also indicates right-hemisphere self-awareness, though the evidence does not necessarily indicate that right-hemisphere self-awareness is fully equivalent to that of the left hemisphere. Insofar as the self-concept depends on reflective consciousness, which is largely verbal, one would not expect a highly developed self-concept in a nonverbal (or minimally verbal) right hemisphere.[7]

In the next section I will describe research by Gazzaniga, who argues that right-hemisphere consciousness is rare in split-brain patients, and that when it occurs it is highly correlated with the presence of language abilities in the right hemisphere.

CONSCIOUSNESS, LANGUAGE, AND BRAIN MODULARITY

Michael Gazzaniga (1983; Gazzaniga and LeDoux 1978) argued that the right hemispheres of most split-brain patients are not conscious. A few split-brain patients have a conscious right hemisphere, and right-hemisphere consciousness is highly correlated with the presence of at least a moderately high degree of right-hemisphere language ability. Furthermore, in his assessment of split-brain patients, those without right-hemisphere language have shown no ability to carry out complex cognitive tasks—beyond basic perceptual recognition—with their right hemispheres.

Evidence for Consciousness in P.S.'s Right Hemisphere

Gazzaniga and LeDoux (1978) first found evidence for right-hemisphere consciousness, associated with right-hemisphere language, in patient P.S., a right-handed, left-hemisphere dominant fifteen-year-old boy. Though P.S.'s right hemisphere could not speak at the time of initial testing, it could spell words by arranging Scrabble letters (letters printed on little plastic squares) with the left hand.

Values and self-concept. Questions were directed to P.S.'s right hemisphere in the following manner: The experimenter spoke aloud the first few words of the question, but the critical final word was flashed to P.S.'s right hemisphere (left visual field) on a tachistoscope screen. Then P.S.'s right hemisphere spelled out the answer by arranging Scrabble letters with the left hand.

> The first question was "Who *are you*?" (Italicized words were flashed to the right hemisphere only.) P.S. spelled "PAUL." The right hemisphere knows its name.
>
> "Would you spell your favorite *girl*? Response: "LIZ." (P.S.'s girlfriend at the time.)
>
> "Would you spell your favorite *person*?" "HENEY WI FOZI" (Referring to Henry Winkler, who played the TV character Fonzie, P.S.'s idol.)
>
> "Would you spell your favorite *hobby*?" "CAR"
>
> "What is *tomorrow*?" "SUNDAY" (Correct.)
>
> "What would you like for *a job*?" "AUTOMOBILE RACE." (This is interesting, because in conversation P.S.'s left hemisphere says that he wants to be a draftsman.)
>
> "What is your *mood*?" "GOOD." (Gazzaniga & LeDoux 1978, p. 143.)

Questions of this sort indicated that P.S.'s right hemisphere is conscious and has a self-concept, including a sense of personal values. To a large degree the left and right hemisphere agree on their likes and dislikes. But the experimenters noticed that on days when P.S.'s left and right hemisphere disagreed very much, P.S. seemed to be in a worse mood than on days when his two hemispheres were in close agreement. P.S.'s right hemisphere's ability to spell out an answer (rather than merely pointing to one of a few limited choice stimuli, as in most split-brain tests) indicates self-generated, voluntary behavior.

On the question of dual consciousness in P.S., Gazzaniga and LeDoux (1978) concluded:

> Thus, it would appear that the right hemisphere, along with but independent of the left, *can* possess conscious properties following brain bisection. In other words, the mechanisms of human consciousness *can* be split and doubled by split brain surgery.
>
> Because P.S. is the first split-brain patient to clearly possess double consciousness, it seems that if we could identify the factor that distinguishes his right hemisphere from the right hemisphere of other split-brain patients, we would have a major clue to the underlying nature of conscious processes. That factor is undoubtedly the extensive linguistic representation in P.S.'s right hemisphere. As we have seen, his right hemisphere can spell, and in addition, it can comprehend verbal commands, as well as process other parts of speech and make conceptual judgments involving verbal information. While it is possible that the conscious properties observed in his right hemisphere are spuriously associated with these linguistic skills, the fact remains that in all other [split-brain] patients, where linguistic sophistication is lacking in the right hemisphere, so too is the evidence for consciousness (1978, p. 145).

Understanding action verbs. Though the right hemispheres of some earlier split-brain patients could recognize spoken or printed nouns (object names), the right hemispheres of Gazzaniga's P.S. and a newer patient, V.P., have the unusual ability to show their understanding of action verbs by performing the actions indicated by them. They can make appropriate responses to verbs such as "laugh" or "rub," or to nouns that imply actions, such as "boxer," when the words are flashed to the right hemisphere (LVF).

When asked to name the word that had been flashed, the left hemisphere (which had not seen the word) makes a guess based on the action that was being carried out (see Figure 5.7). Sometimes the guesses are wrong, though they are reasonable interpretations from the evidence available to the left hemisphere. For example, when the word "walk" was flashed to the right hemisphere, the patient started to leave the testing area (a trailer parked in front of his house). When asked what he was doing, he said "Going to my house to get a Coke."

Emotional reactions. When P.S.'s mute right hemisphere saw the word *kiss*, the left hemisphere blurted out "Hey, no way, no way. You've got to be kidding." When he was asked what it was that he would not do, he could not say. Later, when *kiss* was flashed to the left hemisphere, he replied "No way, I'm not going to kiss you guys!" The interesting thing about the kiss episode is that it suggests that the right hemisphere could recognize a word, have an appropriate emotional reaction to it, and communicate the specific emotional reaction to the left hemisphere without communicating the word itself. There seems to be a direct communication of emotion between hemispheres. (The explanation of this in P.S.'s case probably lies in the fact that, though his corpus callosum was completely severed, his anterior commissure was left intact. The anterior commissure connects the bilateral halves of

FIGURE 5.7. Split-brain subject's responses to commands flashed to the left visual field (right hemisphere). The right hemisphere made a vocal or manual response to the word, then the left hemisphere tried to interpret the response and guess what the word was. The responses to "laugh" and "rub" were ambiguous, and the left hemisphere made a reasonable but incorrect guess. The response to "boxer" was less equivocal, and the left hemisphere guessed correctly. [From Gazzaniga, M. S. & LeDoux, J. E. (1978). *The Integrated Mind*. New York: Plenum Press. By permission of the publisher.]

the [subcortical] limbic system, whose structures [hippocampus, amygdala] are critically involved in emotional reactions.)

In other research with P.S. it was shown that his right and left hemispheres could independently evaluate words, such as "Dad," "Liz," "school," on a five-point like-dislike scale. The two hemispheres usually agreed on their evaluations. Furthermore, the left hemisphere could accurately evaluate words flashed only to the right hemisphere. This indicates a direct communication of an emotional reaction between right and left hemispheres, even though the left hemisphere did not know what the right hemisphere had seen.

A dramatic implication of the observations on P.S. is that even in normal people the speaking, conscious left hemisphere may sometimes detect emotional reactions without knowing their cause. This happens because emotions may be elicited by stimuli not attended to by the verbal system, for example, odors that were associated with emotional reactions in past experience. In such cases the left hemisphere may try to interpret the feelings, making use of whatever information is available. For example, a pleasurable emotion might be attributed to the person we are with, or the scene we are looking at, when unknown to the left hemisphere the pleasurable reaction is really elicited by an odor associated with past pleasures. The left hemisphere's interpretations of our emotional reactions and behaviors may be a fundamental source of our values and beliefs (Gazzaniga 1985; Gazzaniga and LeDoux 1978).

The Interpretive Cortex and the Illusion of Mental Unity

In more recent work, Gazzaniga (1985, 1988a) has identified consciousness with a left-hemisphere interpreter system. In his view, the mind/brain system is made up of a number of modules. *Modules* are relatively independent functional units that can receive information, compute, store and retrieve memories, trigger emotional reactions, and produce behavior. Ordinarily, they cannot make verbal responses (they have no access to the verbal response system), though they can produce other types of overt responses. The modules are nonconscious in that we do not have direct introspective access them, so we cannot make introspective verbal reports on their computational activities, though we may be aware of their outputs or responses.[8] A special module, the *interpreter system*, tries to interpret the diverse actions of the various modules, to explain why they occurred, and to fit them into the narrative sequence of events of our lives and conscious experience. The interpreter system ordinarily occurs only in the left hemisphere, and it probably occurs only in humans. *Consciousness* is associated with the activity of the interpreter system:

> Consciousness in my scheme of brain events becomes the output of the left brain's interpreter and those products are reported and refined by the human language system. The interpreter calls upon an untold number of separate and relatively independent modules for its information (Gazzaniga 1985, p. 135).

Though the interpreter normally occurs only in the left hemisphere, in close association with the language system, it is not the language system itself. "The 'interpreter' idea is not bound by language. . . . Language and speech systems merely report out the activities of the interpreter" (Gazzaniga 1989, personal communication). The separability of the interpreter and the language system is indicated by recent evidence that, under some conditions, a module may produce a correct verbal response to a stimulus even though the conscious interpreter system cannot identify the stimulus (Gazzaniga 1988a).

We have already seen several examples of the left hemisphere's interpretations of the right hemisphere's responses. For example, recall Sperry et al.'s (1979) subjects' verbal responses to photographs seen only by the right hemisphere. Also, P.S. and V.P.'s interpretations of the right hemisphere's responses to action verbs (Figure 5.7). Additional observations on P.S. provide more evidence for a conscious interpreter in the left hemisphere. The two experiments to be described here were done during two different postoperative phases. The first, in Phase I, was during the time when P.S. could understand spoken and written words and spell with the right hemisphere, but could not speak with the right hemisphere. The second experiment was done in Phase II, when P.S.'s right hemisphere had started speaking, which occurred three years after his surgery.

Experiment I. P.S. was seated before a projection screen and a row of eight choice pictures (Figure 5.8). His task was to point to the choice picture that best went with a picture flashed on the screen. When two pictures were flashed on the screen simultaneously, one to each hemisphere, the right hand pointed to a choice picture related to the picture flashed to the left hemisphere (RVF), and the left hand pointed to a choice picture that went with the picture flashed to the right hemisphere (LVF). Both hemispheres performed at a high level.

The most interesting point, however, was the left hemisphere's verbal interpretations of the left hand's behavior. For example, in Figure 5.8, when asked "What did you see?", P.S. responded "I saw a claw and I picked the chicken, and you have to clean out the chicken shed with a shovel" (Gazzaniga and LeDoux 1978, p. 148). The left hemisphere knew only what it had seen, namely, the chicken claw flashed in the RVF, and the choice stimuli selected by each of the two hands. It did not know that the right hemisphere had seen the snow scene. So it interpreted the left hand's selection of the shovel in terms of the chicken theme. Similar results were obtained in other tests with P.S.

Experiment II. After P.S.'s right hemisphere started talking, it was possible to test him with a new procedure (Gazzaniga 1983, 1985). P.S. was shown a series of slides with words, flashed one after another, as in Figure 5.9. If a normal person were to read the words, he or she would tell a simple story: "Mary Ann may come visit into the township today." But P.S. could not read the words left to right. He could read them only sequentially, for each

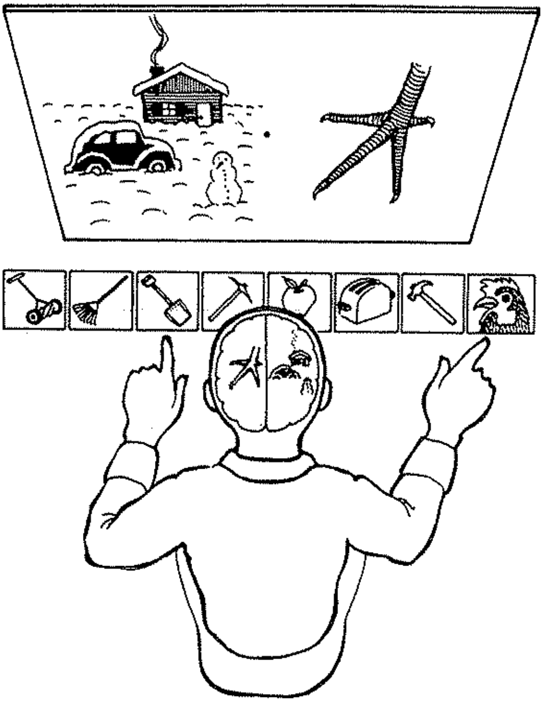

FIGURE 5.8. Method of presenting two matching tasks simultaneously to the split-brain patient, P.S. Different pictures were flashed simultaneously in the left and right visual fields. The subject's right hemisphere (left hand) chose a picture that went with the one it had seen in the left visual field, while the left hemisphere (right hand) chose a picture that matched what it had seen in the right visual field. Then the left hemisphere tried verbally to explain the responses. [From Gazzaniga, M. S., & LeDoux, J. E. (1978). *The Integrated Mind.* New York: Plenum Press. By permission of the publisher.]

hemisphere separately. Thus, P.S.'s left hemisphere read (silently, from the RVF) "Ann come into town today," while the right hemisphere read (silently, from the LVF) "Mary may visit the ship."

After the whole story was presented, P.S. was asked to say what he had read. The left hemisphere (which was still dominant for conversational speech) immediately responded, "Ann come into town today," reporting what it had seen. Then P.S. was asked if that was the full story. He paused briefly and blurted out, "on a ship . . . to visit . . . to visit Ma." This addition must have come from the right hemisphere, since the left hemisphere did not know what the right hemisphere had seen. Finally, when he was asked to repeat the whole story, he replied, "Ann came into town today to visit Ma on the ship." The final report from the left hemisphere told the whole story, making use of what it saw and what it heard the right hemisphere say. Gazzaniga concluded:

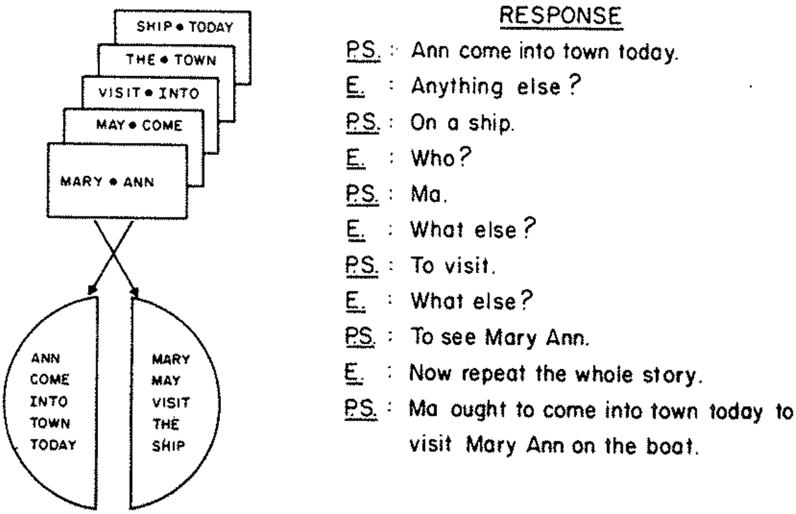

FIGURE 5.9. Method of presenting two stories simultaneously, one to each hemisphere of split-brain subject P.S. A series of word pairs was flashed on the screen sequentially, with one word in each visual field. The left hemisphere quickly reported its whole story, then the right hemisphere reported its story in fragments. Finally the left hemisphere combined the responses into a single coherent story. [From Gazzaniga, M. S. (1983). Right hemisphere language following brain bisection: A 20-year perspective. *American Psychologist, 38,* 525–37. Copyright © 1983 by the American Psychological Association. Reprinted by permission.]

> Once again we see the integration of disparate behaviors into a coherent framework. With the development of bilateral access to speech, behaviors generated by the right hemisphere, which now initiates the spoken word, are incorporated into the conscious stream of the left hemisphere (1983, p. 535).

Modules and mental unity. Based on the test results of P.S. and other patients, Gazzaniga (1985) suggested that many human behaviors and emotional reactions are initiated by nonconscious modules. Such behaviors are automatic or unwilled, in the sense that they are not voluntary acts of the conscious interpreter system. The interpreter system then explains or rationalizes to itself the unwilled actions—such as impulsive violent or lustful behaviors—making a plausible story based on what it knows. The interpreter can also make introspective verbal reports on its interpretations. But the interpreter's accounts cannot be entirely accurate because it does not have direct access to all of the inputs and computational activities of the nonconscious modules—it only knows their responses.

The implication of Gazzaniga's account is that mental unity is an illusion. Our actions are not all controlled by a conscious executive system. Most of them, including many complex cognitive acts, are the products of nonconscious modules. Yet our culturally instilled, folk-psychological belief in conscious control of our actions is so strong that when the left hemisphere interprets the behaviors elicited by nonconscious modules, it typically interprets them as if they had been consciously controlled. Thus, the interpreter system gives us an illusion of conscious mental unity.

Gazzaniga has extrapolated the idea of the interpreter system to account for a wide variety of conscious experiences. The interpreter generates conscious emotional reactions, such as love, anxiety, or depression, through its interpretation of physiological responses produced by nonconscious modules (1988b). The interpreter also is responsible for constructing systems of values and beliefs, including personal, religious, and scientific beliefs (Gazzaniga 1985, 1988a).

Discussion of Gazzaniga's Ideas

You may have noticed a shift in emphasis over the course of this section on Gazzaniga's research, from the early discussion of consciousness in P.S.'s right hemisphere to the later discussion of the conscious interpreter system of the left hemisphere. It seems that Gazzaniga's ideas on consciousness have changed as new research results have become available. Let me try to summarize and interpret this change.

In 1978 Gazzaniga and LeDoux interpreted P.S.'s Scrabble-letter responses to personal questions, and other data, as evidence for consciousness in the right hemisphere. They (and Gazzaniga 1983) argued that right-hemisphere language is rare among split-brain patients, and that without language the isolated right hemisphere is passive and simple-minded. Only when the right hemisphere has "extensive linguistic representation" can it carry out complex cognitive tasks and show evidence of consciousness. Gazzaniga's ideas have had several critics: (1) Myers (1984) argued that Gazzaniga underestimated the frequency of right-hemisphere language ability, by counting split-brain patients whose right hemispheres were damaged (by epilepsy) prior to surgery. Among undamaged right-hemispheres, word recognition (though not speech production) is fairly common (Levy 1983; Zaidel 1983). (2) Levy (1983) argued that a right hemisphere without language can be active and spontaneous and perform complex tasks involving space perception and spatial construction. Only badly damaged right hemispheres are passive and simple-minded.

The extent of right-hemisphere language ability and its relation to intelligent action and consciousness is still a matter of controversy among specialists, and it is difficult for the nonspecialist to sort out the conflicting claims. In any case, more recently Gazzaniga (1985, 1988a) seems to have backed off on associating consciousness with the linguistic system. Consciousness is now associated with the "output of the left-brain interpreter system." The interpreter occurs in close association with the linguistic system, but is not identical to it. The linguistic system merely reports the activities of the interpreter system.

The separability of the conscious interpreter from the linguistic system has been shown in several experiments (Gazzaniga 1988a). For example, the right hemispheres of subjects with right hemisphere word recognition (JW), or with both word recognition and speech production (PS and VP), did poorly at inference tasks that presumably require the interpreter system. In one demonstration, two words were flashed successively to the right hemisphere (such as "pin" and "finger"). In a multiple-choice test, pointing with the left hand, the right hemisphere could not reliably choose a word showing the causal implication of the two words ("bleed"), even though it could choose simple associates of each word (pin, needle; finger, thumb). The implication of this research is that right hemisphere language ability does not necessarily indicate the presence of an interpreter system in the right hemisphere.

Where does this leave right-hemisphere consciousness? If consciousness is identified with the activity of the interpreter system, the implication is that the right hemisphere is not conscious, even in split-brain patients who have some degree of right-hemisphere language ability. Responses previously interpreted as indicating right-hemisphere consciousness are now interpreted by Gazzaniga (1985, 1988a) as the product of nonconscious right-hemisphere modules that can perform some cognitive tasks, generate emotional reactions, and initiate actions. Only the left-hemisphere interpreter is truly conscious, and it interprets some of the right-hemisphere responses to create an illusion of conscious unity. The right hemisphere can carry out relatively simple cognitive tasks, but there is no clear evidence for a complex interpreter system in the right hemisphere. A further implication is that animals are not conscious, insofar as they do not have an interpreter system.

In reply to Gazzaniga, let us grant that humans have some sort of system—call it the "interpreter system"—that carries out complex cognitive functions of interpretation and inference, and that this system ordinarily occurs only in the left hemisphere in split-brain patients. The point of argument is whether consciousness is to be identified only with the interpreter system. I suggest that to limit consciousness to the interpreter system is to set too high a criterion for consciousness. Recall from Chapter 1 the idea of levels of consciousness, in which I distinguished between primary consciousness and reflective consciousness. In some important respects, Gazzaniga's interpreter system idea is similar to the idea of reflective consciousness. Reflective consciousness tries to interpret our actions and experiences, relates them to our past experiences and self-concept, and makes introspective verbal reports on its observations and interpretations. Reflective consciousness deals with some (though not all) of our primary conscious experiences. Having language ability does not necessarily imply having reflective consciousness or an interpreter system, though linguistic thought is involved in the more complex aspects of human reflective consciousness, interpretation, and inference.

The research by Sperry (subjects NG and LB; Sperry et al. 1979) and Gazzaniga (subjects PS, VP, and JW) suggests primary consciousness in the right hemispheres of their split-brain subjects.[9] Both primary and reflective consciousness can vary in complexity and comprehensiveness, both between subjects and between hemispheres. These subjects' right hemispheres have perceptual experiences, emotional reactions, and the ability to recognize and evaluate words or pictures, carry out simple cognitive tasks, and initiate spontaneous responses. Higher-level cognitive functions of reflective consciousness, complex linguistic thought, and interpretation and inference processes appear to be restricted mainly, or entirely, to the left hemisphere.

But the right-hemisphere appears to be conscious in itself, in its own right. It is nonconscious only from the viewpoint of the left hemisphere, which cannot directly introspect and verbally report the right hemisphere's experiences. If my interpretation is correct—that primary consciousness can occur independently of language or the interpreter system—then the possibility remains for primary consciousness in simpler organisms, such as animals and young children, who do not have those abilities.[10]

The research by Gazzaniga and his colleagues has made important contributions to our understanding of mind, brain, and consciousness. We can anticipate that future work will clarify the answers to questions about the nature of the nonverbal modules and what they do, and the relationships between consciousness, language, and the interpreter system.

LEFT-BRAIN, RIGHT-BRAIN MANIA

The empirical findings from the split-brain research have been interpreted, misinterpreted, overgeneralized, and extrapolated to reach conclusions far removed from the actual data. Of course it is customary for researchers to form speculative hypotheses based on limited data. But some of the generalizations and speculations have gone so far from the data, especially in the popular press, that a word of caution is in order.

Numerous articles in the popular press have contrasted the intuitive, creative right hemisphere with the rational left hemisphere. Critics of the schools bemoan the overemphasis on teaching the verbal left hemisphere, and call for programs to educate the right hemisphere and draw on its talents. Under the label of "hemisphericity," some people are thought to be more left-brained while others are more right-brained, according to their preferred styles of thinking. Some teachers try to classify children as left-brain learners or right-brain learners, and design teaching programs accordingly. Eastern meditative practices are advocated as a way to free the right hemisphere, which is presumably repressed in Western culture. The public's fascination with and ready acceptance of left-right dichotomies has gone so far that it has been called "left-brain, right-brain mania" (Gazzaniga 1985, p. 47).

The fascination with simple left-right dichotomies has roots in antiquity, in various cultures. The right and left hands have been associated, respectively, with male and female, good and evil, day and night, rational and intuitive (Corballis 1980). (The English word "sinister" is derived from a Latin word meaning "on the left side." Left-handers are "sinistral.") Some modern writers reverse the traditional left-right associations (associating left with rational, for example), since we now know that the left hemisphere controls language and the right hand.

For centuries philosophers—and more recently, psychologists—have advocated various dichotomies to summarize what they see as fundamental distinctions in human ways of thinking. Some of these dichotomies are summarized in Table 5.1. Note that there is a family resemblance between the concepts within each column.

TABLE 5.1 Dichotomies of Mind

Convergent	Divergent
Intellectual	Intuitive
Deductive	Imaginative
Rational	Metaphorical
Vertical	Horizontal
Discrete	Continuous
Abstract	Concrete
Realistic	Impulsive
Directed	Free
Differential	Existential
Sequential	Multiple
Historical	Timeless
Analytical	Holistic
Explicit	Tacit
Objective	Subjective
Successive	Simultaneous

From Springer, S. P., & Deutsch, G. (1985). *Left Brain, Right Brain* (Rev. ed.). New York: W. H. Freeman. Copyright © 1981, 1985 by Sally P. Springer and Georg Deutsch. Reprinted with permission of W. H. Freeman and Company.

Much of the modern fascination with left and right hemispheres can be traced to Robert Ornstein's book, *The Psychology of Consciousness*, first published in 1972. In the "bimodal consciousness" model, Ornstein (also Bogen 1969) argued that various mental dichotomies such as those shown in Table 5.1 represent two different modes of consciousness, and that the two modes are due to the different cognitive styles of the left (verbal, rational) and right (spatial, intuitive) hemispheres, respectively. The dual modes of consciousness are said to exist simultaneously within the normal (unsplit) human brain. However, such extrapolations from split-brain data to statements about modes of consciousness do not stand up to close scrutiny (Corballis 1980; Gazzaniga 1985). They involve a series of generalizations and analogies that go beyond the data.

Since the first split-brain operations there has been a progression of labels used to describe left and right hemisphere functions (Springer & Deutsch 1985). Table 5.2 shows the most widely used labels, which form a hierarchical five-step series. At each level the labels usually include and go beyond the characteristics in the preceding levels. The labels at the top of the list are based on experimental evidence, the second level labels are based on controversial interpretations of available evidence, while the next three levels involve analogy and metaphor that go progressively further from the evidence. The general public, not knowing the nature and limitations of the actual data, has accepted the interpretation "rational left brain, intuitive, creative right brain" as if it is based firmly on the facts, which it is not.

It is easy to understand why Ornstein's reasoning has been so popular.

TABLE 5.2 Progression of Labels

LEFT HEMISPHERE	RIGHT HEMISPHERE
Verbal	Nonverbal, visuo-spatial
Sequential, temporal, digital	Simultaneous, spatial, analog
Logical, analytical	Gestalt, holistic, synthetic
Rational	Intuitive, creative
Western thought	Eastern thought

Source: Modified from Springer, S. P. & Deutsch, G. (1985). *Left Brain, Right Brain* (Rev. ed.). New York: W. H. Freeman.

It has seemed to provide a respectable scientific foundation for certain popular philosophical, religious, and psychological ideas. If materialist scientists do not take those ideas very seriously, they surely take the brain seriously, and linking philosophical and psychological dichotomies with particular parts of the brain makes them seem more respectable, more like "hard" science rather than mere "soft" philosophy and social science.

Distinctions between different styles of thinking and related philosophical, religious, and psychological theories may have great merit in their own right. But it is an inaccurate oversimplification to link them with one hemisphere or the other. A more accurate view is that in the normal brain different styles of thinking (rational, intuitive, imaginative) are complex processes that involve the interaction of different subsystems (or modules) within each hemisphere as well as interactions between the right and left hemispheres. Creative writing, for example, requires the special abilities of both hemispheres. Furthermore, recent evidence indicates that even relatively simple tasks (such as the blocks-design test) previously thought to be the specialty of a single hemisphere are often performed better by the intact brain than by the single (right) hemisphere (Gazzaniga 1988a, 1989).

SUMMARY

As background to the discussion of neuropsychological research in this chapter and the next, this chapter opened with a brief overview of the organization of the brain and nervous system, with an emphasis on four lobes of the cerebral cortex: occipital, temporal, parietal, and frontal. The "split-brain" operation involves severing the corpus callosum, a large tract of neurons that connects the left and right cerebral hemispheres. Testing the cognitive abilities of a single hemisphere requires that stimulus inputs and response outputs be limited to that hemisphere. This is done by taking advantage of the principle of contralateral organization, whereby each hemisphere receives sensory inputs only from the opposite side of the body, and controls movements of the opposite side. Test results show that in typical right-handed patients only the left hemisphere can speak. The right hemisphere can make pointing responses (with the left hand) to show that it recognizes objects, as well as common words in some cases. The right hemisphere is superior to the left in visual-spatial tasks, such as discriminating between similar-looking faces; the superiority is most apparent in tasks that require drawing or construction of patterns (such as the blocks-design test).

The question of dual consciousness—whether split-brain patients have a separate, independent consciousness in each hemisphere—boils down to the question of whether the right hemisphere is conscious, since there is no doubt about consciousness in the speaking left hemisphere. The difficulty in deciding the issue is that the right hemisphere cannot make introspective verbal reports. Sperry argued that consciousness can occur without language, and that a pattern of intelligent behavior (adaptive, spontaneous, flexible) is a suitable criterion for consciousness. Several types of evidence suggest right-hemisphere consciousness, including cognitive task performance, "alien hand" incidents, behavioral cross-cueing between hemispheres, and self-recognition and a sense of personal values.

Gazzaniga argued that the brain is composed of a number of relatively independent, nonverbal, modules that can process information, make decisions, and produce emotional reactions and overt behaviors. Consciousness is the output of a special interpreter module, which creates a sense of conscious unity by interpreting the outputs of various nonverbal, nonconscious modules, which makes cause-and-effect inferences, and which can make verbal reports on its activities. The interpreter system normally occurs only in the left hemisphere, in close association with the linguistic system, but it is not identical to the linguistic system. Right-hemisphere cognitive activity is carried out by nonconscious modules, in Gazzaniga's view. I suggested that Gazzaniga's interpreter system is similar to the idea of reflective consciousness, and the evidence suggests that both the left and right hemispheres have primary consciousness, but reflective consciousness may be limited to the left hemisphere.

Finally, some popular extrapolations from the split-brain research were discussed, whereby the two hemispheres have been identified with alternative "modes of consciousness" (left: analytical, rational; right: holistic, intuitive, creative). Though these modes of thought are important in their own right, the attempt to enhance their scientific validity by linking them with the individual hemispheres goes beyond the research evidence. In normal brains, complex cognitive activities use the abilities of both hemispheres.

ENDNOTES

[1]It is unnecessary for our present purposes to go into detail on the structure of neurons and neural networks, the chemical processes of neurotransmission, or other aspects of fine brain structure such as the columnar organization of neurons. Nor will we be concerned here with more detailed aspects of gross neuroanatomy, such as the peripheral nervous system. For readers wanting to review these elements, most general psychology textbooks provide an adequate introduction (for example, Atkinson et al. 1987; Darley et al. 1991). For more advanced discus-

sions see textbooks in physiological psychology (such as Carlson 1986; Rosenzweig & Leiman 1989) or neuropsychology (Kolb & Whishaw 1990).

[2]Left-hemisphere language is true of virtually all right-handed people, and about 70 percent of left-handed people. Roughly 15 percent of left-handed people have reverse dominance, with language functions in the right temporal lobe. Another 15 percent have mixed dominance, with language functions divided between the two temporal lobes. It has been speculated that mixed dominance is not the best way to organize language functions, and this may be related to the fact that left-handed people are statistically somewhat more likely than right-handed people to have speech and reading difficulties.

[3]For a striking case study of visual agnosia, see the title story of *The Man Who Mistook His Wife for a Hat*, by neurologist Oliver Sacks (1987). Sacks' book contains some twenty-four very interesting and readable case studies of patients with different types of brain damage and defects. For example, the chapter titled "The Lost Mariner" describes a Korsakoff's syndrome patient with severe amnesia. In *The Man with a Shattered World*, Alexander Luria (1987) described the case of a brain-injured war veteran whose speech and verbal thinking were severely impaired, but whose will-power led him to devise a strategy for writing his own autobiography. Both Luria (1973, 1978, 1987) and Sacks (1987) stressed the point that in most cases brain-injured people strive actively to compensate for their injuries. It is an oversimplification to talk about the deficits caused by injuries. Brain-injured individuals are still people with lives to live and goals to fulfill. They use the sensory, motor, and intellectual abilities that are still intact to compensate and navigate through life as well as possible. However, successful adaptation depends on having relatively intact frontal lobes to make plans and control voluntary actions.

[4]In their animal research, Myers and Sperry cut both the corpus callosum and the optic chiasm. This operation created a subject in which the left hemisphere could see only with the left eye, and the right hemisphere could see only with the right eye. (To be precise, the left hemisphere could see only the right visual field, through the left half of the retina of the left eye [and vice versa for the right hemisphere], as explained in Figure 5.3.) Thus, the monkey's left hemisphere could be trained on a visual discrimination by covering the right eye, so only the left-eye/left-hemisphere could see. With the left hemisphere in control, the monkey used its right hand to respond to the test stimuli (recall the principle of contralateral organization); the left hand was restrained. Subsequently, to test what the right hemisphere knew, the monkey was tested with its right eye open (left eye covered) and left hand free (right hand restrained).

[5]Subjects chose faces matching the left side of the chimera regardless of whether they pointed with their left hand or their right hand. This result can be explained by the fact that each hemisphere has some degree of movement control over its *ipsilateral* (same side) hand, even though the dominant control is contralateral. Thus, the right hemisphere can control gross pointing movements of the right hand, though it cannot control fine-skilled right-hand movements.

[6]It is worth noting here that Howard Gardner (1985) has presented evidence that there are several specialized "intelligences" that can solve problems in different spheres of activity, using different sorts of mental codes, mostly nonverbal. The six intelligences discussed by Gardner are: linguistic, musical, logical-mathematical, spatial, bodily-kinesthetic (movement, as in dance and athletics), and personal (including social relationships and self-understanding). Conscious thinking is implied in the flexible, adaptive control of various specialized activities by these specialized intelligences or mind-brain subsystems. Gardner's theory of specialized intelligences contrasts with the older theory of a single, general-purpose intelligence.

[7]Extrapolating from the evidence for dual consciousness in split-brain patients, some writers (Puccetti 1981) have suggested that dual consciousness—independent consciousness in each hemisphere—also occurs in normal brains. The dominant hemisphere normally suppresses the nondominant one, and the split-brain operation merely reveals a double consciousness that was always there. However, few researchers support this idea. Those who accept the evidence for dual consciousness in split-brain patients argue that dual consciousness was created by the commissurotomy (see commentaries following Puccetti 1981).

[8]Gazzaniga's conception of modules as "functional units that can produce behaviors and trigger emotional responses" is broader than the conception of modules proposed by other theorists (such as Fodor 1983; Schacter 1989), who see modules as more narrowly specialized computational subsystems that contribute to broader functional systems, such as language and men-

tal imagery systems (Gazzaniga 1988a). Gazzaniga mentioned modules for visual perception, visual mental imagery, and face perception. But like most writers, he declined to provide a detailed list of modules and their functions. That is a challenge for future research.

[9]Gazzaniga (1985) hinted at the possibility of right- hemisphere primary consciousness in a passage where he said that nonverbal modules should not be characterized as nonconscious merely because they "cannot internally communicate with the dominant hemisphere's language and cognitive system." A nonverbal module "is very conscious, very capable of [making decisions and] effecting action" (p. 117). He used the term "coconscious but nonverbal mental modules," but he did not expand on this conception. Instead he continued to emphasize the association of consciousness with the interpreter module, which has direct access to the verbal system.

[10]As we will see in later chapters, others besides Gazzaniga have proposed an intimate link between consciousness and interpretation processes. Either consciousness is an interpreter system, or conscious experience results from, or is influenced by, an interpreter system or interpretation processes. Just as there are different levels of consciousness, there are different levels or types of interpretation procesess. Thus, it is not strictly correct to say that reflective consciousness involves an interpreter system but primary consciousness does not. Rather, primary conscious experiences (such as sensory perception and dreaming) involve lower levels or different types of interpretation processes than those involved in reflective consciousness. Similarly, the disconnected right hemisphere might be better characterized as using lower level interpretation processes, rather than by the complete absence of a right-hemisphere interpreter system.