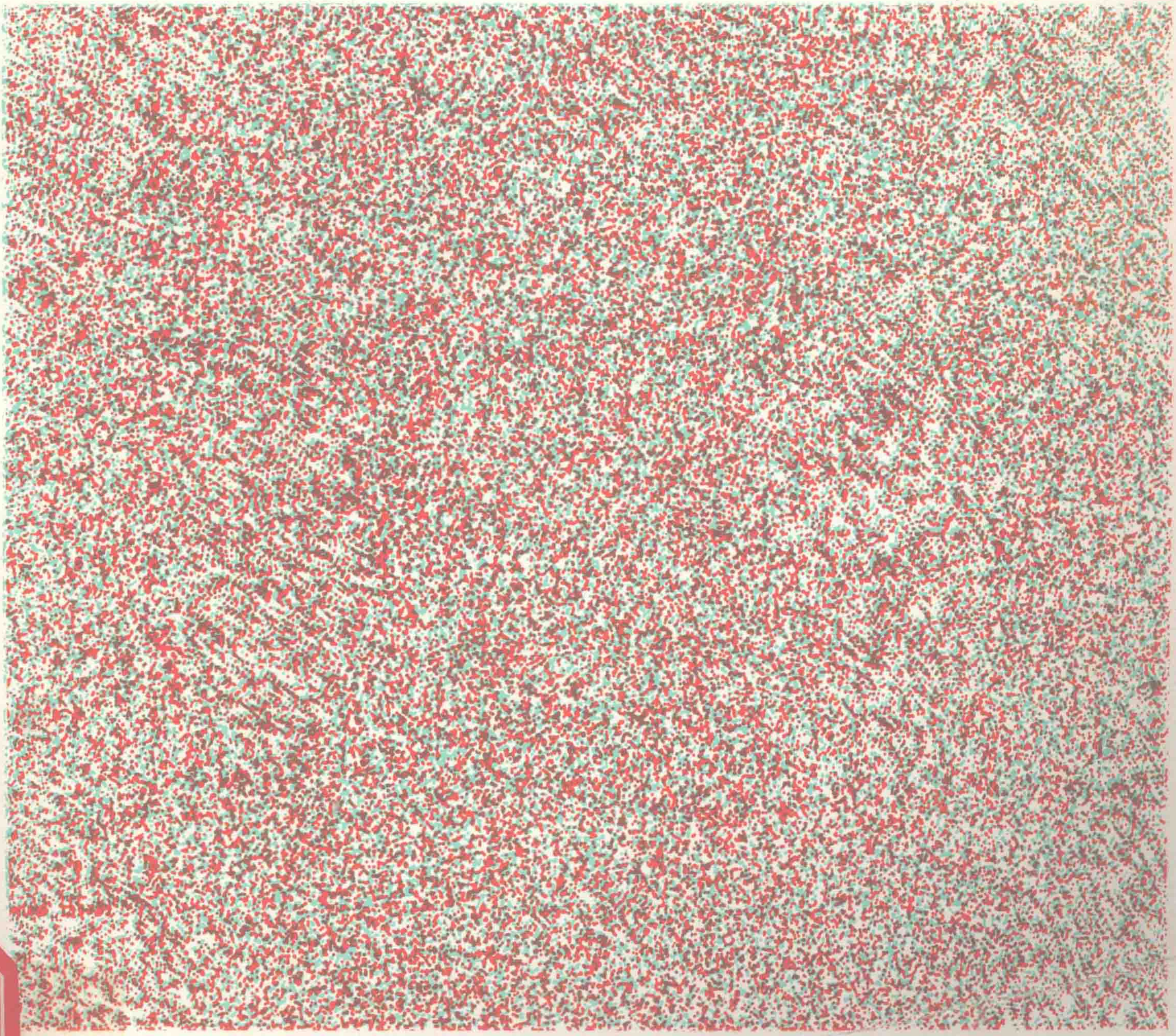
Current Trends in Psychology

Readings from **American Scientist**

Edited, with Introductions, by **Irving L. Janis,** Yale University
Member, Board of Editors, *American Scientist*



Use the red-green viewer included in this book to reveal the visual phenomena shown here and discussed on pages 173–184.

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Contents

Introduction

The intent of this book of readings is to provide beginning students and interested laymen with a representative selection of the most promising lines of research now being carried out by leading psychologists. Present-day psychology deals with an astonishing range of human problems, both practical and theoretical. Psychologists realize that in the past decade their field has experienced a publication explosion (well over 12,000 research papers on hundreds of topics are listed annually in *Psychological Abstracts*). No one can keep up any longer with everything going on in psychology. The most advanced scholars, as well as graduate trainees, undergraduate students, and laymen, must content themselves with gaining familiarity with only a very limited set of topics. Consequently, a book of readings can serve the vital function of providing a carefully selected sample of the highest quality work representing major trends in current theory and empirical research.

The articles selected for this volume were all written during the past decade by distinguished research psychologists. They discuss a variety of key theoretical ideas and describe major examples of systematic investigations, including some exciting new discoveries at the outermost frontiers of psychology. Taken together, the collection provides in-depth illustrations of some of the best research in psychology during the past ten years, to supplement the panoramic overview of standard topics offered by textbooks.

The selection process actually began long before this volume was planned. Most of the articles were originally prepared at the invitation of the Board of Editors of *American Scientist* with the intention of supplying the journal's 130,000 readers with up-to-date reviews of current theory and significant investigations. The authors invited to prepare such articles are among the outstanding trend-setters in their respective fields.

From the large number of authoritative psychology articles published in *American Scientist* between 1965 and 1976, 39 were selected as suitable both for beginning students and for general readers who are likely to read about psychological research in *Psychology Today*, the *New York Times Magazine*, or other popular sources. Some outstanding articles were left out of the collection because their technical nature made them unsuitable for the general reader, although they were highly appropriate for graduate students. A few of the articles selected for inclusion were re-edited to make sure that every paragraph is clear and precise. In some instances, the authors were asked to rewrite sentences that might not be intelligible to readers who have not had advanced courses in the subject. In other instances, the editor has removed from the text paragraphs and figures that deal with technical details or subsidiary issues not essential to the main theme of the article. All such material is included in the "Notes" at the end of the volume, so that more advanced readers can, if they wish, read each article in its entirety, just as it was originally published in *American Scientist*. Original numbering of illustrations has been retained to alert readers when a figure has been moved to the "Notes."

As a result of the way the articles were selected and edited, anyone who is able to understand a standard introductory textbook in psychology (and is willing to dip into one occasionally to fill in gaps in his background) should readily comprehend the main points in the articles included in this book of readings. If he takes the trouble to read all the articles, the reader will learn what leading psychologists have to say about where the real excitement lies in basic psychological research and will acquire an excellent perspective for understanding current trends.

The eminence of the authors of the articles is attested by a few facts about professional recognition of their achievements: ten have been elected to the National Academy of Sciences and nine to the American Academy of Arts and Sciences; six have received the Distinguished Scientific Award of the American Psychological Association; four have received the Warren Medal of the Society of Experimental

Psychology; three have received the Socio-Psychological Prize of the American Association for the Advancement of Science; and six have received other major research awards, such as the Kittay International Award and the National Medal of Science. Many of the younger contributors can be expected to receive similar honors for their research in the years to come.

The articles are divided into five major areas, which correspond to standard chapter groupings in most psychology textbooks and in the *Annual Review of Psychology:* (1) Psychobiology; (2) Developmental Psychology; (3) Cognitive Psychology; (4) Personality, Motivation, and Emotional Stress; and (5) Social Psychology. These areas are, of course, interrelated and overlap considerably. Some articles, particularly those in the section on Developmental Psychology, could be categorized in more than one area.

Despite the overlap, there is no single, generally accepted theory that spans all the areas. Nor is there even a single master theory within any one area that is accepted by a consensus of specialists working in the area. Instead, one finds a multiplicity of "miniature" theories that explain why or under what conditions certain limited types of observable behavior occur. The articles within each area provide ample opportunities for perceiving the diversity of viewpoints as well as for comprehending a substantial sample of the most precisely formulated and carefully tested miniature theories. In the more developed areas, particularly in psychobiology and cognitive psychology, some of the emerging theories go beyond the miniature, encompassing ever larger clusters of phenomena and pointing the way to reconciliation of ongoing internal controversies.

The recent findings reported in the articles in all five areas challenge many of the generalizations widely accepted by earlier generations of psychologists, usually replacing oversimplified formulations with more complex models that take account of multiple causes of behavior. We shall see that many relationships thought to be as simple and straight as a breadstick turn out to be pretzel-shaped, requiring pretzel-shaped theories to account for them. In the introduction to each area, the new developments in theory, as well as recent trends in research methodology, will be described briefly and related to the specific findings discussed in the articles. These introductions are intended to serve several functions. First, they enable course instructors to see what kinds of theory and research are covered in each section, which may help them decide whether to use this book of readings and, if so, which articles to assign. Second, each introduction gives readers an overview of recent developments in the area, with a bird's-eye view of the main ideas they will encounter. Third, the introductions include a brief summary of the main points of every article in the section, to which students can return after having read the articles, whenever they want to refresh their memories.

Irving L. Janis
New Haven, Connecticut

PART 1 *Psychobiology*

In recent years, research on biological aspects of behavior has advanced on many different fronts, including the functioning of the nervous system, the effects of hormones on behavior, and the role of genetically fixed predispositions. Advances have also been made in understanding the relationship of biological evolution to the adaptive behavioral changes that have evolved in different species of animals, including man. These topics, well represented by the nine articles in the opening section, are subsumed under the general heading of psychobiology. The articles delineate major theoretical approaches and experimental methods now being used by scientists who are contributing to our knowledge of psychobiology. They present authoritative accounts of some of the exciting discoveries that are opening up new vistas in this rapidly developing field.

Jacob Bronowski, in his educational television series, subsequently published as a book, *The Ascent of Man,* has described a shift in the focus of attention of science during the past two decades, from the physical sciences to the life sciences. One of the great successes in modern biological research to which Bronowski referred, along with the unraveling of the heredity code in the DNA double helix, is the work on the functions of the human brain, which he characterized as a prime achievement in man's cultural evolution.

Recent advances that relate specific psychological processes to specific brain functions are presented by Michael S. Gazzaniga in the first article, "One Brain—Two Minds?" Gazzaniga takes as his starting point the amazing discovery that when the two hemispheres of the human brain are separated in an operation which severs the corpus callosum, their connecting link, the patient shows evidence of having two separate "minds" that "coexist as two completely conscious entities." What the right side of the brain sees, learns, and remembers is not available to the left side, and vice versa. Gazzaniga concludes from the intensive experimental studies on split-brain patients that without an intact corpus callosum a man's consciousness is no longer unified, which drastically affects his language, thought, memories, and all sorts of subjective experiences.

While primarily concerned with increasing basic knowledge about how the two hemispheres of the brain operate, the research has already pointed the way to practical advances for rehabilitating certain kinds of brain-damaged patients. Gazzaniga describes a study in which he and his collaborators developed a new way of training aphasics who had lost the power of speech because of damage to the left brain hemisphere. By teaching them a symbolic code that does not require the use of words, the investigators were able to produce a dramatic improvement in the patients' ability to communicate.

The second article, "Are Stages of Sleep Related to Waking Behavior?" by Laverne C. Johnson, is a comprehensive review of a vast body of research dealing with brain waves in relation to observable behavior. After it became possible to obtain electrical recordings of the brain and of the muscles of the eye half a century ago, researchers began to report surprising discoveries, which led some of them to announce broad generalizations that captured the imagination of an entire generation of physiological psychologists and neurophysiologists—for example, the claims that changes in brain waves during sleep show a dependable series of four distinctive stages, that the restorative functions of sleep depend on a stage of sleep characterized by very slow brain waves, and that dreams occur only during the stage accompanied by rapid eye movements (which might show that the dreamer is literally looking at the visual images of his dream). In the light of the cold, harsh facts from recent laboratory studies, Johnson informs us, some of these well-known claims are overgeneralizations that need to be reformulated.

The new findings come from improved techniques of making electrical recordings of brain functioning, combined with the use of computers that provide research workers with reliable quantitative analyses of the unbelievably complex mixtures of signal and noise in the masses of data obtained from the electrical recordings. Johnson shows that the earlier studies on four stages of sleep stand up very well but that previous studies on behavioral correlates of those stages do not. Although vivid dreams continue to be elicited from human subjects who are awakened during the rapid-eye-movement (REM) stage of sleep, similar results are obtained to some extent from other stages as well. Hence depriving people of the REM stage of sleep can no longer be described as "dream deprivation." Nor does the accumulated evidence support the earlier claim that the REM stage satisfies a need for dreaming, which if frustrated generally leads to hallucinations and delusions during the waking state. After reviewing a considerable body of evidence, Johnson surmises that it may be more fruitful to investigate disruption of the regular sleep-waking cycle rather than to continue to observe the effects of depriving the sleeper of any particular stage of sleep. He believes that this shift is likely to be productive in the search for an explanation of why sleep deprivation has deleterious effects on mental efficiency in the waking state.

In the next article, "The Evolution of the Stress Concept," the great pioneer Hans Selye discusses basic causes of psychosomatic disorders and relates his most recent findings on hormonal changes to his earlier classic work on biologic stress. Selye starts with a summary of evidence that led him to postulate a three-stage "general adaptation syndrome" as a response to severe stress. Initially, there is an alarm reaction, then a stage of adaptation or resistance, and finally a stage of exhaustion if the stressor is severe and lasts a long time. One of Selye's major conclusions from a long chain of research investigations is that widely different stressors—including exposure to heat, cold, painful injury, bereavement, signs of imminent danger, and all sorts of exciting news, good or bad—all produce essentially the same general physiological changes, together with a variety of specific effects. Among the most important of the nonspecific changes described by Selye are increased secretions of hormones by the adrenal gland, which can lead to circulatory disorders, peptic ulcers, kidney damage, and numerous other "diseases of adaption" to stress, depending upon the presence or absence of specific pathogens and the predispositions of the individual that make him more prone to one disease than another.

From his recent research, Selye introduces a new conception of how the hormonal changes work. He postulates two distinct ways by which homeostasis of the inner environment of the body is modified when it survives an invasion by pathogenic stressors. One of the mechanisms, which Selye calls *syntoxic,* allows for "peaceful coexistence" with the invader. The other, which he calls *catatoxic,* triggers active attack and destruction of the pathogen. Selye describes how these two mechanisms can lead to different psychosomatic disorders.

In addition to the hormonal changes described by Selye, many other hormonal secretions can modify activity of the nervous system in ways that directly and indirectly affect a person's behavior. In the next article, "Behavioral Endocrinology: An Emerging Discipline," Frank A. Beach, a noted authority on behavioral effects of hormones, presents a comprehensive synthesis of present knowledge on this topic. Much of the research he describes shows how sexual behavior is affected by increases and decreases in gonadal hormones. Beach's review also takes note of a recent "growth spurt" in the field, with rigorous experimental methods being used to study the effects of hormones in man and lower animals on learning, feeding, sleeping, adjusting to stress, and social interaction.

The evidence Beach cites for drawing generalizations about both sexual and nonsexual aspects of human behavior comes from clinical studies of people with endocrine disorders as well as from animal experiments on the effects of varying hormone levels in the organism's bloodstream. In line with current interest in mediating mechanisms, Beach discusses the ways hormones can temporarily alter an adult organism's behavior and how in the developmental stages they can produce irreversible changes in the anatomy and physiology of the nervous system, which permanently affect behavior.

Another approach to the study of how the nervous system mediates behavior is reported in Masakazu Konishi's article, "Ethology and Neurobiology." This approach builds on the classic work of the great ethologists Konrad Lorenz and Niko Tinbergen regarding external stimuli called *releasers.* Such stimuli evoke in all animals of a given species a specific set of behavioral responses, which serve for capturing prey, escaping from predators, copulating, or some other potentially adaptive form of behavior. Lorenz's observations were reported to the scientific world in the 1930s, but until very recently it was unclear how releasing stimuli affected the nervous systems of insects, molluscs, birds, and mammals that showed adaptive responses to releasers. Scientists could only guess at what might be going on inside; the nervous systems of those organisms remained mysterious black boxes. Konishi reports on recent discoveries made by several scientists who have used sophisticated techniques for detecting the electrical activity of single neurons in response to releasers. These studies have opened up the black boxes for systematic scrutiny.

What the scientists are finding inside those black boxes, however, is creating turmoil among the ethologists. The new hard facts on the physiological bases of the behavioral mechanisms originally described by Lorenz, Tinbergen, and other pioneers in ethology reveal that their widely accepted theories are too simplistic and in some important particulars have to be revised drastically. In some species, according to Konishi's account, the releasers turn out to affect only the peripheral sense organs, not the central nervous system; in others, there are distinct stages of "stimulus filtering" that involve higher centers of the nervous system. Gone are the days when investigators could hope to account for all the effects of releasers by a single general principle.

One of the liveliest areas of psychobiological research that has come into prominence during the past decade is the study of the biological basis for social behavior of animals—so lively that it is front-page news. On 28 May 1975, a front-page story in the *New York Times*, replete with photographs and line drawings, reported the work of scientists who investigate common patterns of group behavior across the animal kingdom. What is newsworthy, according to the science reporter, is that recent research carries "the revolutionary implication that much of man's behavior toward his fellows, ranging from aggressive impulses to humanitarian inspirations, may be as much a product of evolution as is the structure of the hand or the size of the brain." At present, among specialists in animal behavior there is considerable skepticism about any direct extrapolations to man like those highlighted in the *New York Times* story. Heated controversies continue about how to interpret the complicated findings now at hand from this flourishing branch of psychobiology. But despite the controversies, considerable progress is being made in solving long-standing problems concerning social dominance, aggression, altruistic behavior, and communication within animal societies. A sample of recent contributions, including some fascinating findings on common components in the social behavior of animals, including man, is presented in the last four articles in this section.

In a comprehensive review of the evidence on aggressive behavior among primates, "The Function of Aggression in Primate Societies," Irwin S. Bernstein and Thomas P. Gordon dispel a number of popular myths about so-called natural tendencies of man's closest relatives in the animal kingdom. One long-prevalent myth is that when a troop of primates is confronted with threatening intruders, the females are generally more acquiescent and less aggressive than the males. Not so, according to systematic observations of a variety of species of monkeys described by Bernstein and Gordon. Another myth clearly refuted by the evidence is that primates generally compete with each other for any desirable resource that is in short supply in their environment. Restriction of the food supply in the wild not only fails to produce the expected increase in aggressive competition among hungry monkeys but actually leads to a decrease, with all their energies devoted to foraging.

Hungry or not, both male and female primates respond with vigorous physical aggression to one major form of provocation—the introduction of an outsider into an established group. Bernstein and Gordon cite a large number of field and laboratory studies in support of the conclusion that aggression arises primarily in response to predators and intruders who threaten disruption of established social ranks and privileges, rather than to loss of food, sexual partners, or other sources of reward. The authors point out that this dependable aggressive tendency may well have been shaped by natural selection, with feuding inside the group kept to a minimum and with altruistic self-sacrifice on the part of the most aggressive members having the effect of increasing the chances for survival of fellow members who have similar genes.

The article by P. H. Klopfer and M. S. Klopfer, "How Come Leaders to Their Posts? The Determination of Social Ranks and Roles," describes a series of field studies of goats. Some of the findings show that when the environmental conditions change in ways that affect the food supply, the presence of predators, or other features that affect survival of the herd, the type of goat that becomes dominant and its functions as leader also change. Differences in sociability and dominance appear very early in the behavior of newborn kids but can be markedly affected by the way their mother treats them. For example, the mother may lick with her tongue the most vigorous feeder in a way that equalizes nursing opportunities for the less vigorous kid.

The dominant sibling in a litter of kids does not necessarily become a dominant leader, because other factors, such as changes in population density, also influence emergent leadership. Klopfer and Klopfer point out that observations of the variability in the crucial leadership attributes that are favored in different environmental circumstances can be interpreted in terms of survival value for the herd. Changes in environmental conditions require corresponding changes in leadership capabilities to induce the herd to share food or to engage in selfish hoarding, to stick close together or to disperse.

Peter Marler's article, "Birdsong and Speech Development: Could There Be Parallels?" highlights the relevance of animal studies on vocalization and intergroup communication for understanding human speech. Marler calls attention to some unexpected parallels between man and certain species of birds. The species he describes are those for which there is a critical period of 10 to 50 days during the first months of life when each individual's ability for vocal learning is at a peak and when hearing vocalizations of adults in the flock has a lasting effect on subsequent development. Just as in human speech development, preventing the young bird from hearing the model's vocalizations and its own imitations of the model prevents adequate learning and results in permanently abnormal vocalizations. And just as in the human brain, the brains of various species of birds have been found to have a dominant hemisphere, with vocalization centers located primarily on the left side.

Marler acknowledges that the enormous phylogenetic distance that separates man from birds makes it unlikely that the specific parallels which have been found are based on the same physiological mechanisms. He argues, however, that detailed studies of the way bird songs are learned and maintained may illuminate the biological framework of human speech, particularly the adaptive value of lateral dominance in brain functioning and constraints on what will be learned from adult models.

In the final article in this section, "Behavior Programs and Evolutionary Strategies," Ernst Mayr takes a position long advocated by leading ethologists, namely that adaptive behavior in all species can be analyzed as the result of selection pressures during the course of evolutionary development. Using concepts from molecular biology and information theory, he reformulates the old questions and answers about which behaviors and how much of them are determined by *innate* genetic endowment as against *acquired* experience. His new formulations, which contribute to the demise of this antiquated dichotomy, rely on an important differentiation between two types of genetic programs—closed and open. Closed programs, which are widespread among insects and other lower animals, give rise to fixed behavior patterns that are highly similar in all individuals of the species and that remain unmodified throughout the life of each organism. Open programs, which presumably are more common among primates and other higher mammals, allow for greater flexibility in response to changes in the environment.

From a broad survey of behavior patterns that promote survival, Mayr concludes that closed programs are adaptive when there is only one required response to a stimulus, as in courtship, recognition of offspring, and termination of hostile behavior among members of the same species. Open programs, according to Mayr, are likely to govern food-seeking and other actions oriented toward making use of natural resources, which require accommodating to rapid change in the environment and shifting to new niches. A central theme of Mayr's article is that open and closed programs can account for evolutionary changes in behavior through natural selection, which he illustrates with well-known examples of imprinting, innate releasing mechanisms, ritual signaling, territorial defense, and dietary shifts in new habitats.

Mayr's integrative concepts pose a challenge to the thoughtful reader to reexamine the findings described in the preceding articles on psychobiology in terms of an evolutionary perspective that takes account of both open and closed genetic programs. His analysis points the way to fruitful use of an evolutionary perspective that is potentially applicable to all forms of animal and human behavior. It requires examining the selective advantages of each important behavior pattern that is "molded by evolution" and investigating the "selection pressures" set up by that pattern, which in turn can initiate subsequent evolutionary changes of behavior.

Michael S. Gazzaniga

One Brain—Two Minds?

The behavioral consequences of sectioning the cerebral commissures raise fascinating questions about the physical basis of conscious behavior

The idea of consciousness stands out alone as man's most important, most puzzling, and most abused problem. Most other human ideas pale in complexity next to this one and to the long series of associated questions surrounding the nature of brain and mind. Indeed, upon studying the problem and reading the literature, one cannot help but conclude that the only subjects of greater mystery are the articles written about or around the problem of consciousness.

It is difficult if not impossible with our present knowledge to define explicitly what is meant by conscious experience. What I mean by the term can be illustrated by considering what you the reader presently feels. It is the dimension which makes you more like a dog than a computer. Since this is hardly a sophisticated or formal notion, we talk about the *functions* of consciousness in order to make the subject of consciousness scientifically manageable. Thus eating, drinking, reading, loving are all analyzed in their separate parts. By studying these aspects of conscious activity we hope to gain some understanding of the whole idea of consciousness. In real terms, of course, how such processes relate to brain mechanisms remains unknown. Yet it is these kinds of questions that arise when considering the problems of the bisected brain in both animal and man.

Michael S. Gazzaniga, Professor of Psychology at SUNY, Stony Brook, did both his graduate and postgraduate work in psychobiology at California Institute of Technology. He continued in postgraduate study at the University of Pisa and then went to the University of California, Santa Barbara, where he became Associate Professor and Chairman of the Psychology Department. He has written The Bisected Brain *and more than forty articles and chapters in the field of psychobiology. The research reported here has been largely supported by grant MH1788-3 from the National Institute of Mental Health. Address: Department of Psychology, State University of New York, Stony Brook, NY 11794.*

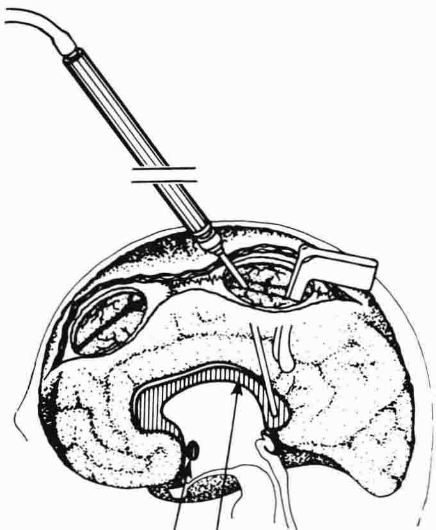


Figure 1. Both a frontal and a posterior opening are made in the split-brain operation. The corpus callosum and anterior commissure are sectioned in one operation.

Over the past ten years we have collected evidence that, following midline section of the cerebrum, common normal conscious unity is disrupted, leaving the split-brain patient with two minds (at least)—mind left and mind right (*5*, *25*). They coexist as two completely conscious entities, in the same manner as conjoined twins are two completely separate persons. This view has been contested by a variety of people (*2*, *19*). In what follows we will first review the basic findings of the split-brain phenomenon and then report on several recent advances that give further support to our view that two minds can exist in one head.

In many ways, the split-brain phenomenon is as startling and basically mysterious today as when R. E. Myers and R. W. Sperry first discovered it in animals in the early fifties. As experimental animal evidence for the double-brain phenomenon developed and expanded to include the monkey and the chimpanzee, the question became: Could a human being be considered to have double consciousness as a result of midline section of the cerebral commissures? Could a pass of the surgeon's knife produce two separate and distinct coexisting mental entities both within one head—each operating outside the realm of awareness of the other?

In recent experiments on both animals and man, additional supportive evidence has accumulated for the double mind view. Studies examining the neural substrates involved in setting response probabilities, as well as preliminary work examining cortical-hypothalamic interactions, all argue for the double mind view. In addition, our ongoing work on teaching left brain-damaged patients an artificial language gives support to the earlier view of the natural mental capabilities of the right-half brain.

General review

Clearly, in man the issue of "double mind" is more dramatic than in the animals. In most of the following we will be talking about double mind as it exists in split-brain patients. All of a group of several patients operated on by Dr. P. J. Vogel and Dr. J. E. Bogen, at the California College of Medicine (*7*), were epileptics, and the aim of the surgery was to prevent the interhemispheric spread of seizures. To this end, the great cerebral commissure, the corpus callosum, which spans the midline of the brain and interconnects the two half brains, was sectioned in one operation (Fig. 1). In addition, a second, smaller commissure, the anterior commissure, was also cut.

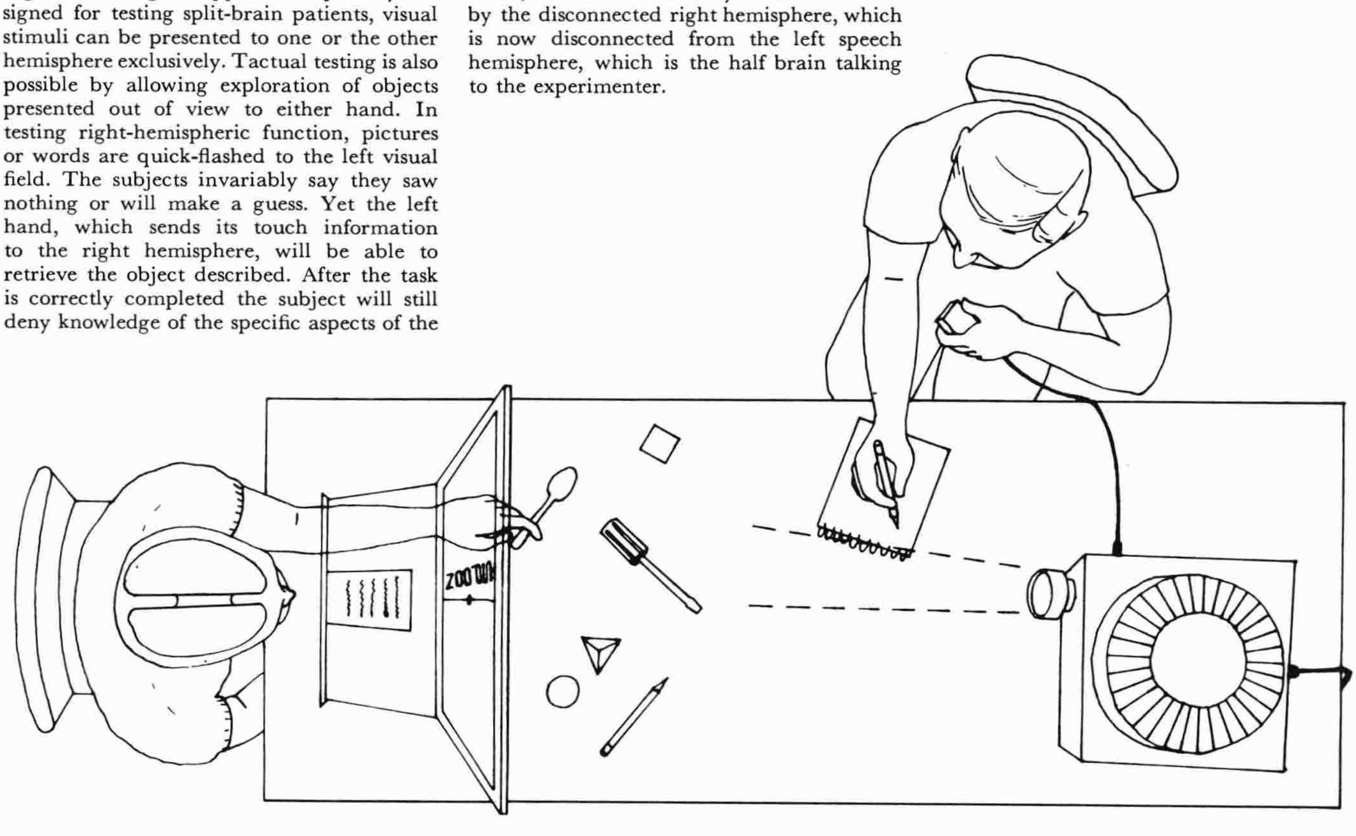
Therapeutically the operation has been largely successful. Behaviorally, the patients for the most part appear entirely normal, and the untrained observer would be unable to ascertain that brain surgery had ever been performed. It is only under special testing conditions that the peculiar phenomena reveal themselves (*5*). The left hemisphere, because of its intact language and speech system, can fully communicate its thoughts and ideas; it seems to be normal and conscious. It is the right hemisphere's status that is both crucial and difficult to ascertain. It does not have a speech system and thus cannot tell about its experiences through speech. We have circumvented this problem by using nonverbal response procedures (Fig. 2). As a result we have been able to define many right-hemisphere functions that can go on independently and largely outside the awareness of the left hemisphere. It can read, learn, remember, emote, and act all by itself. It can do almost anything the left can do, with admitted limitations in the degree of its competence.

Since this original series of studies delimiting the syndrome of cerebral commissurotomy, there have been continuing efforts to extend and further define the behavioral consequences of the surgery. Some of the work emphasizes the role of brainstem processes and the amount of information that can be exchanged at these levels (*27*). Other studies caution against this view and point out how many of these assertions have other explanations (*8, 9*). Still others have analyzed the way such separated hemispheres approach and solve perceptual tasks of all kinds (*26*). These latter studies claim, for example, that the right hemisphere remembers faces in terms of a "gestalt"—of the actual pictorial and configuratory cues—while the left hemisphere is more analytical and tends to remember by analyzing specific features of a face. The idea here is that mind left is poet-like and mind right is the painter in us.

The suggestion that these kinds of observation support the idea of double consciousness (i.e. a separate set of mental controls for each hemisphere) has been challenged by Donald M. MacKay (*19*). He raises a crucial and fascinating question. All organisms have, of course, normative systems. Clearly, in split-brain man, at the physical level, basic humoral and electrotonic brainstem influences are unified and intact. In addition, MacKay wonders whether basic psychological systems such as our response priority-determining mechanism exist in duplicate in these patients. This is the system that sets the goals, priorities, and rank order of objectives of an organism. Put differently, it assigns values or response probabilities—one of the most important features of brain activity. Without this mechanism the world would seem flat and any activity would be like any other. MacKay maintains that this system, which he calls the "metaorganizing system," is a leading and basic feature of brain function and that it is rarely if ever in conflict. As a result, he maintains, it falls to us to demonstrate whether or not each half brain has its own priority-determining system that can work independently of the other.

There are seemingly a lot of things going in favor of MacKay's criticism. Hillyard and I (*9, 12*), for example, have recently shown that the CNV brain wave (i.e. the contingent nega-

Figure 2. Using an apparatus especially designed for testing split-brain patients, visual stimuli can be presented to one or the other hemisphere exclusively. Tactual testing is also possible by allowing exploration of objects presented out of view to either hand. In testing right-hemispheric function, pictures or words are quick-flashed to the left visual field. The subjects invariably say they saw nothing or will make a guess. Yet the left hand, which sends its touch information to the right hemisphere, will be able to retrieve the object described. After the task is correctly completed the subject will still deny knowledge of the specific aspects of the event, because the activity was carried out by the disconnected right hemisphere, which is now disconnected from the left speech hemisphere, which is the half brain talking to the experimenter.



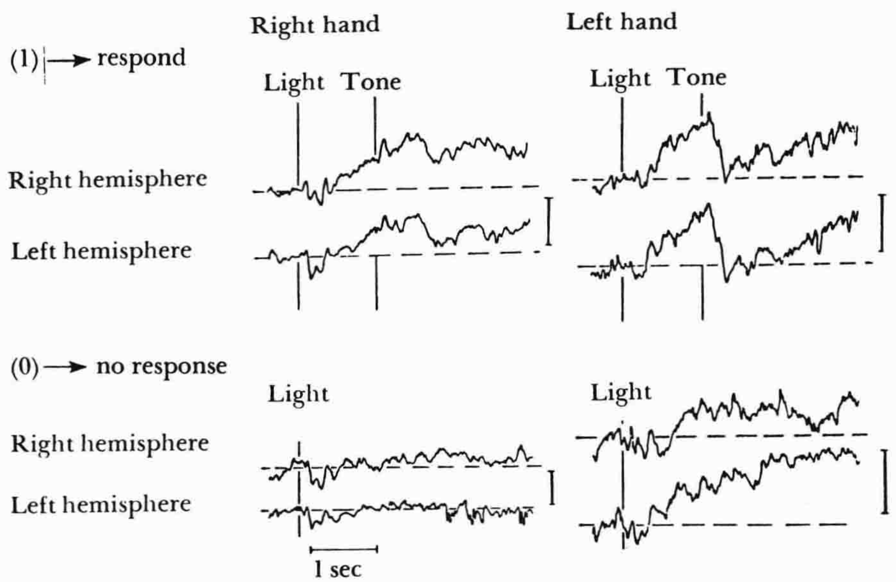


Figure 3. Computer-averaged CNV's (N = 12) recorded simultaneously from the scalp over the right and left hemispheres when right or left hand was used and left visual field–right hemisphere was presented the visual discrimination task. Clearly, both hemispheres develop the expectancy wave even though only one knows what the triggering stimulus was. Nonpolarizing electrodes were placed 5 cm to the right and left of the midline, along the interaural line. Trials containing eye-movement artifacts were excluded from these averages. DC amplification was used; calibrations, 20 uV.

tive variation brain wave that appears over the parietal lobe region prior to a specific motor response) is bilaterally symmetrical, even though only one half brain sees the triggering stimulus (Fig. 3). In this test, recordings were made on each side of the skull while a visual discrimination was flashed to only one hemisphere. The subject was trained to make a manual response to a tone which followed the numeral "one" but did not follow a "zero." Thus, when the "one" appeared the expectancy brain wave develops but does not appear if a "zero" is flashed. When the information was presented in the left visual field, which projects to the right hemisphere, the subject responded appropriately. When subsequently asked what the stimuli were, the subjects said they didn't know—that's the left hemisphere talking. Yet the physiological recordings showed that the normal expectancy wave developed in each hemisphere.

In the past such waves were thought to have a 1-to-1 correspondence to basic psychological processes. While this may still be true, the relation becomes more remote. The separated hemispheres are linked in these parameters but remarkably different in both their subjective and objective reports. The CNV seems to have psychological specificity with respect to the events that trigger it, but it cannot be indexing a psychological process like attention or expectancy because the nonexpectant hemisphere also has the CNV. As a result, what initially looked like a strike for hemisphere unity now appears to be otherwise.

Still the MacKay question is open. Experimentally, the question becomes: Can one environmental situation precipitate two different behavioral responses, each having a different value for each half brain? In other words, could the same rewarding event elicit a different probability of responding in each separate hemisphere?

There is a difference between what I am asking and what has already been shown literally hundreds of times in split-brain cats, monkeys, and humans. A variety of studies have shown that the split-brain organism can learn conflicting visual discriminations. For example, the right hemisphere is trained to learn that the + of a + vs. 0 discrimination will be rewarded in one half brain and the 0 of the + vs. 0 in the other half brain. In this experiment the peanut or reward value is kept constant: the animal has the same probability of responding to it in each half brain. Learning opposing visual discrimination cues as a less probable contingent response is, you might say, a cognitive detail. It does not put the normative system in conflict for the peanut always remains rewarding.

Again, what we are asking is the more basic question: can the more probable response, namely eating the peanut, have a value X for one hemisphere and a value Y for the other? This question was recently analyzed by J. D. Johnson and myself, using split-brain monkeys (*17*). During the course of studying the role of reward in learning it became apparent that the positive stimulus of a visual discrimination, which may become a rewarding event in and of itself in one brain, simultaneously elicited neutral responses in the other half brain.

Consider the following. We have shown that when one naive hemisphere observes the errorless performance of the other on a pattern discrimination, it too learns (*16*). In other words, a half brain need not experience errors to learn a visual discrimination.

Having established that trial and error is not a necessary condition for learning, we next tried to analyze the role of reward. In brief, we taught one half brain a new problem and then advanced the reward schedule to fixed ratio 2 (RF-2). Thus, on every other trial the animal was rewarded (Fig. 4). On the nonrewarded trials, both the trained half brain and the naive half brain were allowed to view the discrimination. On the rewarded trials, only the trained hemisphere saw the problem; the naive half brain saw nothing. Could the naive half brain learn if it only observed correct performance and also never experienced a reward? We supposed that if the normative system (which assigns values or response probabilities to all events) was common to both hemispheres, the monkey would calmly and easily learn the discriminative cues even though there was no primary reward present. The secondary or quasi-reward value of the stimulus ought to register instantly on the naive side.

What happened was most surprising to us. The naive hemisphere not only did not learn the discrimination, but on the nonrewarded trials it actively interfered with the ongoing normal discriminative activity of the trained half brain. In other words, the naive half brain was not content to observe the performance of the trained side on these trials as it had before when rewards were present. It waived any response tendency that might have transferred and sought its own solution to the problem. As a result, it actively intruded and interfered with behavior.

Clearly, any quasi-reward value of the discrimination *per se* that may have been assigned to the stimulus by the trained half brain did not transfer, and was in no way communicated, to the naive half brain. If it had, the naive half brain would have learned easily and would not have been frustrated. Indeed, when looking at the actual behavior, it was as if two different value systems were competing for control over one response mechanism.

These animal studies are in agreement with recent testing of the split-brain patients on the effects of reward (Fig. 5). We showed that when a reward—say, the appearance of the word "right" for correct responses and "wrong" for incorrect responses—was flashed to one half brain and a visual discrimination was presented exclusively to the other, no learning occurred in over thirty trials (*15*). In callosum-intact people, the information is immediately synthesized and learning occurs in one or two trials. Johnson went on to show, however, that if the split-brain patient was reprimanded for making an error, quick learning occurred. Here, it is hypothesized, the reward, or feedback, no longer remained cortical. When the "wrong" light appeared the patient would now make an exclamation, sigh, and gesture disgust. On the next trials, learning occurred. Thus when the reward took on more general affective responses the cuing became so massive that the opposite half brain could figure out which stimulus was producing the general negative reaction and which was not. Taken together then, it can be said that higher-order reward information can remain isolated and separate in the split brain. Each hemisphere apparently is free to assign different or even conflicting response probabilities to the same stimulus.

In a more direct physiological approach to these same general questions, Alan Gibson and I have been analyzing the eating behavior controlled by each hemisphere in split-brain monkeys, following unilateral hypothalamic lesion (*14*). To date we have seen marked differences between the hemispheres in food intake behavior and response patterns as the result of the lesions. In other split-brain animals, differences were discovered that reflected unilateral damage to the hypothalamus as a result of the surgery. What is apparent is that two completely different response probability systems can coexist in the split organism for something so basic as food. That is, one hemisphere will initiate more activity for food than will the other. This must mean that the cortical system, which is the only neural system disconnected in split-brain surgery, is much more involved in the hypothalamic process than we had ever thought.

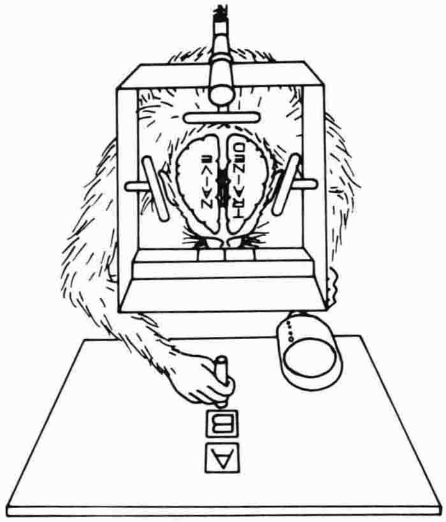


Figure 4. Split-brain monkeys observe a visual discrimination through a specially designed training apparatus which allows for the separate or combined projection of visual information to each eye. Here a naive hemisphere is free to observe the errorless performance of a trained hemisphere.

Language training

The earlier claim of the existence of double consciousness following transection of the cerebral commissures has received support from other studies. At the time, we largely based the idea on the extensive evidence we had collected on the cognitive capacity of the disconnected right hemisphere in man. This mute, passive cognitive system was shown to be capable of a number of mental operations, as outlined above. One inference from this work was that if the left, dominant hemisphere should ever be damaged in a normal adult, the right side with proper training ought to be able to come to its aid. While this idea has received little support from huge amounts of clinical data, it nonetheless seemed viable as a result of our studies on the bisected brain.

Recently, working at New York Institute of Rehabilitative Medicine, Andrea Velletri, David Premack, and I were able to teach an 84-year-old global aphasic some basic language operations (*11*). This woman had had a major stroke involving the left speech and language center that rendered her hemiparalytic and unable to understand or produce natural language. Nonetheless, using the language scheme developed by Premack (*22*) for chimpanzees, we were able to train her to arrange correctly cut-out paper symbols that were referrent to language operations.

Contrary to existing views, which in the main hold that the left hemisphere's language center is specialized for the processing of symbolic information, the subject learned that a variety of paper symbols were each referrent to a particular linguistic operation. For example, when two similar objects were placed side by side, the subject could place between them a symbol meaning "same." When the objects were different, another symbol, representing "different," would be appropriately placed. The proper use of the "same" and "different" symbols was not restricted to the items used in training but transferred freely to non-training items. A question symbol was introduced in the same-different construction and given the meaning of "missing element"; the subject showed her grasp of the symbol by successfully substituting for it whatever element was missing, predicate as well as object. In addition, the subject could form the negative in the injunctive mode. We have extended these observations by training six more global aphasics. Some have been brought to the level of generating simple sentences using these methods.

While, of course, one cannot completely rule out the possibility that undamaged parts of the left hemisphere are active in carrying out these tasks, it would seem fair to say that a more likely explanation is that the remaining right hemisphere is doing the work. In other words, the original split-brain data we reported on humans that spelled out the boundary condition of mental competence on the right side give support to the notion that the right hemisphere, separated or not from the left hemisphere, can do many complicated and sophisticated cognitive operations.

These remarkable abilities in severely brain-damaged global aphasics demonstrate that the languageless human being still possesses a conceptual system that can handle the logical tasks outlined in the foregoing. The data suggest, moreover, that there exists in the brain a conceptual system that is separate and independent from the natural language system. Indeed, it could be that this primitive conceptual system may be the primordial cognitive system of primates, from which may have come the language abilities of man. Approaching the problem of cognition in this light suggests the theoretical importance of coming to a better understanding of the brain-damaged human. With the confounding and interwoven language mechanisms put to rest, we can begin to see how the brain deals with complex logical operations in the raw.

There is other additional support for the view that the right hemisphere has tremendous cognitive powers. We have seen the intact brain at work performing perceptual tasks outside and independent of the normal language system. In some exploratory and preliminary tests (7) carried out at Cornell Medical School, unilateral amytal testing was done on the left hemisphere of two nonaphasic brain-damaged patients subsequent to a required angiogram. Prior to injection of the anesthetic, which has the effect of putting one half brain briefly asleep, an object was placed in the subject's left hand, out of his view. When asked what it was, the subject responded correctly by saying "spoon." This showed that the left hand–right hemisphere somesthetic projection system was working as well as the right hemisphere–left hemisphere callosal link to the speech center. Next, the amytal was administered and the left hemisphere went out. At this time, when the patient is totally unable to use or understand language, another object was placed in the left hand. Since the right hemisphere is exclusively awake, it is free to remember the test object. The subject held it for awhile, and then it was removed. Shortly thereafter, the effects of the drug wore off and the left hemisphere woke up. An exchange followed that went something like this:

"How do you feel?"
"Fine," said the patient.
"What did I put in your hand?"
"I don't know," said the patient.
"Are you sure?"
"Yes," said the patient.

Then a series of objects were shown to the subject. "Which one was it?" The left hand immediately pointed to the correct object.

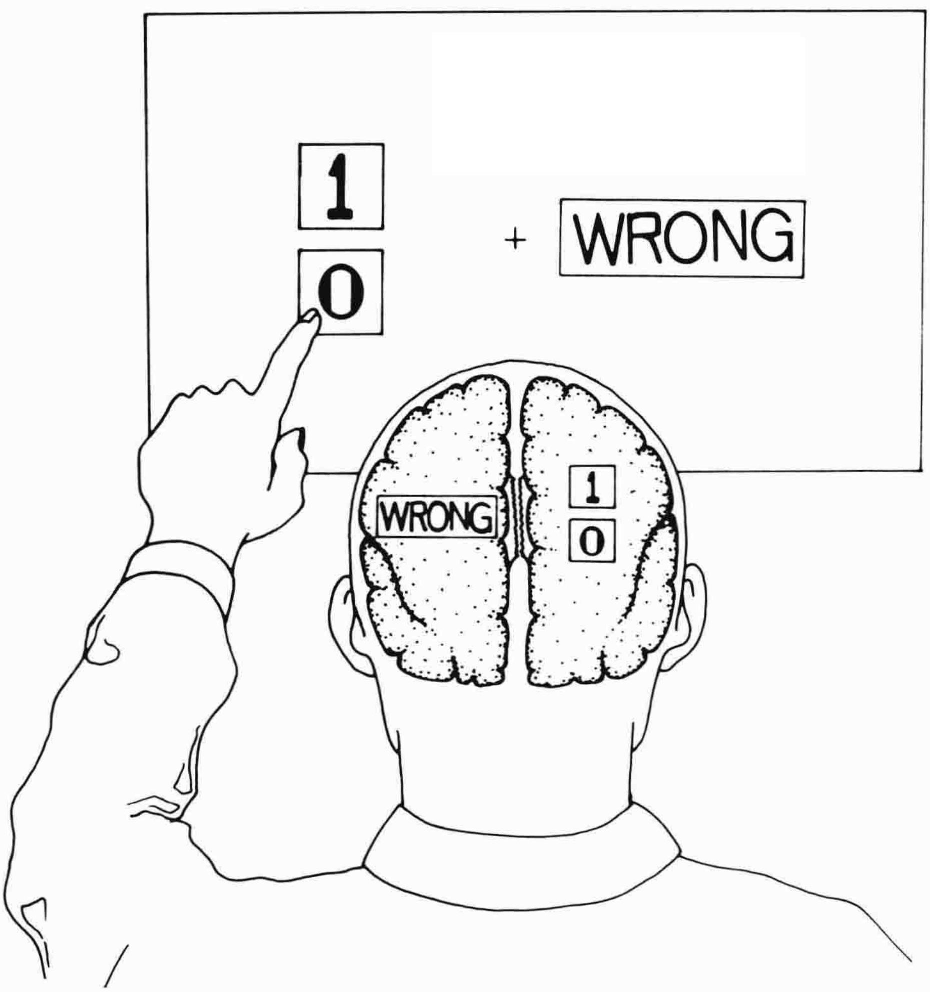


Figure 5. Split-brain subjects are unable to describe verbally from the left hemisphere visual information presented to the right hemisphere (left of fixation). Here a discrimination is presented to the right hemisphere while only the left receives reward information. Normals learn the problem quickly, but a split remains at chance level after 30 trials.

It is still too early to report all the necessary qualifications on this experiment. Other patients, for example, are unable to remember anything at all. Yet, the first result suggests that, when the natural language and speech system is not functioning, perceptually stored information encoded at that time is not subsequently available to the language system upon its return to normal operation. In a way it is like the common experience of being unable to remember events earlier than the age of two or three. It is possible that the brain can remember critical events, which may later play a role in the control of behavior, but because the remembered events occurred prior to the clear establishment of the language system they cannot be subsequently recalled through this system.

Yet the brain is forever confounding its students by continually offering up paradoxes. From some of our recent tests it would seem that the functional capacities of the right hemisphere are present to a different extent when it is tested in the presence of the left hemisphere but disconnected from it versus when it is tested in the presence of a damaged left hemisphere. Many of the positive functions attributed to the right hemisphere come from our studies on split-brain patients. As I have said, simple noun-object discriminations were easily carried out. If we blindfold a subject and tell him to find an object with his left hand, correct performance is invariably seen. Here both hemispheres hear the question while only the right receives the opportunity for answer by stereognostic information from the left hand.

When this test is run on a subject with a minimally damaged left hemisphere no such ability is found (*10*). We recently examined a 63-year-old man with a crisp and nearly pure auditory agnosia. He has no evidence of bilateral disease. He essentially speaks normally, reads normally, and writes normally, yet he cannot understand a single spoken word and was unable to perform the auditory tactile test described for the subjects with split brains! The real differences in functional expression from the right hemisphere as seen in this case suggest that damage to the left hemisphere plays an important role in limiting or inhibiting the upper capabilities of the right hemisphere.

Brain code and the corpus callosum

It is difficult at this point not to mention a major aspiration coming from this work. Those of us in brain research assume that there is a corollary physical code to our personal psychological experience. It has not been at all clear how and where one would approach this problem in the brain, but it now seems that the corpus callosum might be a good starting point. We know beyond a shadow of a doubt that it is this brain structure which relates the psychological, conscious experiences of one hemisphere to the other. Therefore, if we could succeed in gaining insight into the nature of the callosal transfer mechanism, it is possible that we would also find some answers to the more general question of how the brain encodes and transmits psychological data.

It is in this context that we first examined interhemispheric exchange of information in normals. Obviously, in order to begin to understand the corpus callosum, it is necessary to study people in whom it is still intact. Briefly, the original idea was to use lateralized visual stimuli in combination with reaction-time measures in an effort to determine the timing and transfer properties of this great commissure. By asking for a spoken response in a left hemisphere-dominant person, we had hoped to show a difference between the reaction time to incoming stimuli that were originally projected to the left hemisphere, as opposed to information originally projected to the right half brain.

In one of our first studies, we found that when a simple dot was flashed to the left hemisphere, subjects responded approximately 30 msec faster using speech than when it was flashed to the right hemisphere (*4*). The response was to say "yes" when the dot was present and "no" when it was absent. When a trial consisted of a simple flash, the "no" response took approximately 40 msec more than when the left hemisphere was responding to a dot. This was explained by the fact that the left half brain had to wait for a signal from the right as to whether a stimulus had appeared or not. At that time we also showed that there was no reliable difference in this task when a manual response was required.

Along with the dot experiment, we were examining the extent to which each hemisphere in normal man is capable of controlling language processing (*6*). Here we used the Posner and Mitchell "name identity versus physical identity" tasks and demonstrated that tasks requiring verbal processing were done more quickly when the test material was first presented to the left half brain. In this experiment there were two conditions. In the first part subjects were required to respond manually only to physically identical stimuli. Thus AA or aa would require response whereas AB, Ab, or ab would not. The results showed that there was no difference in response rate as a function of left or right visual field presentation. In other words, either hemisphere could perform this task rather easily.

In the second condition, however, the subject was instructed to respond to name identity only—i.e. whether the two adjacent letters were of the same class, such as Aa. Here there was a difference between the two hemispheres. When the information was presented to the right nondominant hemisphere, the response took longer than when it was flashed to the left speech hemisphere.

We next examined whether the interhemispheric exchange relation could be reversed (*13*). We thought by taking a visual-spatial task we could now find right-hemisphere superiority. Using a simple visual pattern task that required subjects to judge which two zig-zag figures were oriented in the same direction, we found that, with a verbal response, the discrimination could be performed much more quickly when presented first to the right hemisphere. When first presented to the left hemisphere, the task takes approximately 14 msec longer to perform. The interpretation is that information needing spatial analysis which is presented to the left hemisphere is first relayed over to the right for decoding and then sent back to the left for the verbal response.

There have been a number of additional observations reported which seem to bear out these early general findings (*3*, *18*, *20*, *21*, *23*). A variety of different tests have been used, and not too surprisingly there have been different observations on the interhemispheric transfer latency. For the most part the tests break down into two main categories: those that deal with the callosal transmission and timing properties and those that are primarily concerned with the different cognitive properties of each hemisphere per se and how they relate to information processing models.

In a sense, of course, these kinds of early studies simply demonstrate that reaction time techniques are sensitive enough to be used to trace information flow in the brain. It remains for these techniques to be used to discover properties of the callosum itself. To this end we have recently been carrying out a series of experiments that require the interhemisphere matching of visual information (*7*). Using this procedure we quickly discovered that interhemisphere matches using difficult-to-see visual stimuli (subjects indicate whether two words are the same or different) are far less accurate when one word is flashed to one hemisphere and the other to the opposite than when both are flashed to the same hemisphere. If the stimuli are bright, crisp, and clear, no such differences are seen.

At the start then we may be faced with the fact that the callosum is a rather limited communication channel. It normally is engaged in communicating the activities of one half brain to the other in a still unspecified spatial-temporal neural code, and it does not easily encode for transmission weak signals presented to one hemisphere. We