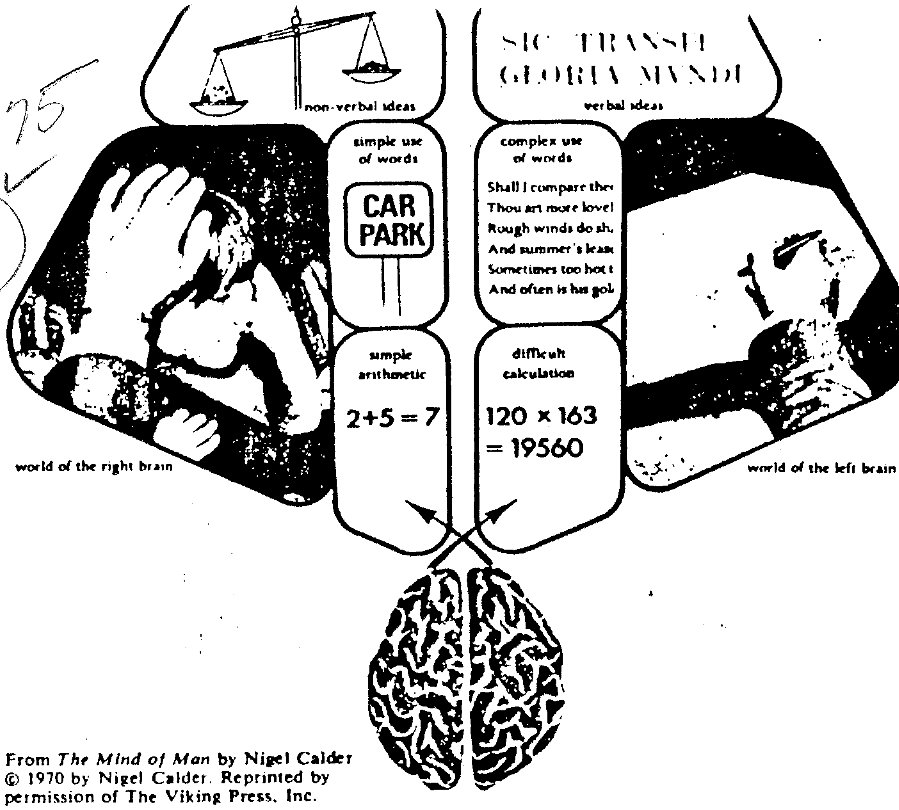

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The two sides of the brain—When split, they act like separate persons.

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Left-Brain, Right-Brain

Our understanding of mind-brain interaction has been vastly altered by studies that now offer a clearer picture of the two brain hemispheres and their specialized forms of intellect.

by Roger W. Sperry

At the upper levels of the brain is a thick bundle of transverse fibers called the corpus callosum, the largest fiber system in the brain, interconnecting the brain's two large cerebral hemispheres. These hemispheres are now commonly known as left-brain, right-brain because, once the corpus callosum has been cut, the two sides of the brain appear to possess such independent capacities and mental properties that each merits a separate name.

The first series of operations creating the split brain in human beings was performed in the late Thirties and early Forties in order to relieve the seizures of persons afflicted with severe epilepsy—the theory being that the corpus callosum transmitted the brain waves which caused the seizures. The operation has proven effective for selected severe cases in minimizing seizures or in stopping them altogether. But the most remarkable effect of this drastic operation was the seeming *lack* of effect on the patient's behavior and personality.

Extensive follow-up studies failed to disclose any definite neurological or psychological symptoms or deficits left by the surgery. That was generally the case in occasional individuals born without a corpus callosum. As late as the early Fifties, the function of the corpus callosum—estimated to contain over 200 million fiber elements, was still an enigma.

This fact prompted my colleagues and studies on surgical sections of the corpus callosum of cats and monkeys. It soon became evident that the surgically disconnected halves of the brain have their own private sensations, percepts, and learning experiences—all cut off from the awareness of its partner hemisphere. We also learned that each brain half stored its own separate chain of memories, which were inaccessible to the other hemisphere.

The split-brained animal, having learned a task with one hemisphere, would have to relearn it all over again from the beginning when it was obliged to use its other hemisphere. Further, the two hemispheres could be trained concurrently to learn mutually contradictory solutions to a task—with no apparent mental conflict. It was as if each hemisphere had a mind of its own.

This finding still did not tell us much about the left-brain, right-brain differences in people, though, because it turns out that human beings are the only mammals whose left and right brains are specialized for quite different *functions*. This phenomenon is correlated with the power of speech and the related talents that separate us so distinctly from all other animals.

Our first opportunity to study a human split brain came in 1961, when a callosum-cutting operation was performed by Philip Vogel and Joseph Bogen of the White Memorial Medical Center in Los Angeles. The patient was a 48-year-old war veteran whose brain had been severely damaged by bomb fragments. The injury afflicted him with terrible convulsive seizures, which continued to worsen in spite of all treatment. Upon recovery from the surgery, he was free of the seizures and seemed quite normal in his everyday behavior; in fact, he even showed a much-improved sense of well-being. But his surface normality seemed to overlie some startling changes in his inner mental makeup—a suspicion we were to confirm in studies of additional subjects who had had the same operation.

Some of the new insights that evolved from these studies have occasioned an enormous burgeoning of interest in the left-brain, right-brain phenomenon—

Roger W. Sperry is Hixon Professor of Psychobiology at Cal Tech. This article is an edited adaptation of a speech Dr. Sperry gave upon receiving the twenty-ninth annual Passano Foundation Award.

among psychologists as well as biologists. In the process new concepts of consciousness and the workings of the human brain have emerged. Because of increasing public demands for relevance in government-funded science, I am often asked to spell out some of the more practical implications of our neuroscientific investigations in terms of medical perspective and changing views of man and the human mind.

But before I talk about left-brain, right-brain, I must go back a step or two. When we first launched our investigation into the functional role of brain connections, one of the first things we learned was how much we had to *un*learn. At that time neuroscience was thoroughly sold on the notion that brain function was infinitely malleable. Among other things, the functional interchangeability of nerves in neurosurgery was taken for granted. Having its "wires" crossed by the neurosurgeon supposedly created no problem at all for the brain back in the Thirties.

In those days if any damage was done to a nerve that normally transmits the necessary messages to, say, the muscles of the face, that nerve would be replaced surgically by a nearby healthy and more expendable nerve, such as the one used in lifting the shoulder. The initial effect would be that the face muscles would move whenever the patient tried to lift his shoulder. However, the doctrine of the day prescribed that if the patient went home and practiced in front of a mirror, those malleable brain centers would shortly undergo re-education to restore normal facial expression, now mediated through the brain centers and nerves designed for shoulder movement.

At the same time, efforts were being made to restore function to legs paralyzed by spinal-cord lesions. The technique involved using one of the main nerves of the *arm* without disconnecting that nerve from the brain centers. The arm nerve was dissected out, full-length, then tunneled under the skin, and connected to the leg nerves so that it would take over the function of the paralyzed limb. Only an early report of this procedure—*not* the final, disappointing outcome—appeared in the literature, for perhaps understandable reasons. Nevertheless, exactly the same operation was later (in the Thirties) reported to be a functional success in experimental tests with rats. The motor, the sensory, and even the reflex functions of a paralyzed hind limb were said to have been restored through the transplanted nerves (working via the brain centers) of the forelimb. Thus even scientists, trying to follow the most objective standards, now and then deceive themselves in the direction of their preconceptions.

In those days the nervous system was generally supposed to be possessed of a wholesale behavioral plasticity or, as one authority put it, "a colossal adaptation capacity almost without limit." The followers of Pavlov in Russia and John Watson in this country were speculating that it should be feasible to shape human nature into virtually any desirable mold and thus to create a more ideal society, by means of appropriate early training and conditioning.

This kind of thinking was reinforced by other views current in the Thirties. In particular, the prevalent doctrine concerning nerve growth told us that during embryonic, fetal, and early childhood development, fiber outgrowth and the formation of nerve connections in the brain were essentially diffuse and nonselective. That is, a nerve would connect as readily in one place as it would in another, as in any good standard household wiring system. There seemed to be no way by which the nerve circuits that governed behavior could be grown into the brain directly—that is, *pre*-functionally, through inheritance, without being shaped by experience. It was supposed that the adjustment in brain connections depended *entirely* on function and that it began during the earliest movements of the fetus *in utero*, continuing from then on through trial and error, conditioning, learning, experience, through any means but heredity. Our experimental findings in the Forties, however, effected a 180-degree about-face in our understanding of these matters. As we now know, nerves are *not* functionally interchangeable. The brain is not all that malleable, and the growth of nerve paths and nerve connections in the brain is anything but diffuse and non-selective. Neural circuits for behavior are definitely grown in, pre-functionally, *under genetic control*—and with great precision in an enormously complex, pre-programmed, biochemically controlled system.

This brief historical review is not just an excuse to recall old times. The point is that while all this has now become a matter of history for those of us in the biomedical sciences, the early views that became so deeply entrenched all through the Twenties, Thirties, and well into the Forties have still not been completely shaken off in other areas. The lingering aftereffect of these doctrines may still be found exerting an unwarranted influence on related disciplines, such as psychiatry, anthropology, and sociology, as well as on society at large. The result is that the majority of us still have a tendency to underrate the genetic and other innate factors in behavior.

"Within the brain we pass conceptually in a single continuum from subnuclear particles, to molecules, to cells, to cerebral processes with consciousness."

What dictates which hemisphere is dominant, whether the individual will be left-handed or right-handed? A recent theory put forth by Jerre Levy of the University of Pennsylvania and Thomas Nagylaki of the University of Wisconsin (both formerly at Cal Tech) proposes that there are two genes governing cerebral dominance and handedness. Each of these two genes has two versions, or "alleles"; thus there are four in all. One gene determines which hemisphere of the developing brain will be language-dominant, and a second gene determines whether the preferred hand will be on the same side as, or opposite, the language hemisphere. Without going into the details, if we count up the possible dominant and recessive characteristics contained in these few genes, we come up with nine different combinations of inherited genotypes, each with distinct properties of cerebral dominance and handedness. Some of the left-handers, for instance, will be more resistant than others to reversal by training, because of their genetic pattern.

Now, both the left and right hemispheres of the brain have been found to have their own specialized forms of intellect. The left is highly verbal and mathematical, performing with analytic, symbolic, computerlike, sequential logic. The right, by contrast, is spatial and mute, performing with a synthetic spatio-perceptual and mechanical kind of information processing that cannot yet be simulated by computers. When one is dealing with neurosurgical patients whose left and right hemispheres have been surgically disconnected, it is most impressive and compelling to watch a subject solve a given problem like two different people in two consistently different ways, using two quite different strategies—depending on whether he is using his left or his right hemisphere.

In other words, the nine combinations of genotypes, representing different balancing and loadings of left and right mental factors, provide just in themselves quite a spectrum for inherent individuality in the structure of human intellect. Left-handers as a group have been shown to be different statistically from right-handers in their mental makeup—that is, in IQs and in other test profiles. Similarly, the profiles of males are different from those of females. And females masculinized *in utero* or those lacking one X chromosome are shown to be different from normal females.

Many kinds of tests have shown that the right hemisphere is particularly talented and superior to the left in visual-spatial abilities. This specialty of the so-called minor hemisphere, according to a recent report in the *American Journal of Human Genetics* by Darrell Bock of the University of Chicago and Donald Kolakowski of the University of Connecticut, is tied to a recessive sex-linked gene; that is, a gene linked to the X chromosome, of which the mother has two and the father has only one. In any case, the specialty is shown to exhibit a cross-correlation pattern of inheritance from parents to offspring in such a clear-cut manner that this aspect of cerebral dominance is seen to be purely genetic and other theories dealing with environment, experience, or child development as being responsible for it are ruled out. Because of the distinctly hu-

Eyes Left! Eyes Right!

A simple but striking instance of the left-brain, right-brain dichotomy is the way it affects one's eye movements. The characteristic direction of these movements often yields interesting information about a person's attitude and ways of thinking.

To test this proposition, have someone look at you while you ask questions that might be handled by either brain hemisphere. Say, for example, "If you were President, how would you deal with the Middle East situation?" Or, "What is the meaning of the proverb, 'Better a bad peace than a good war'?" You will see that the subject's eyes glance (and frequently his head also turns) in one direction as he begins to reflect about the answer. Some look quickly to the left; others look first to the right. The direction of gaze of most persons is reasonably consistent (78 to 80 percent of the time in the same direction). The direction of this initial flickering shift, at the moment of pondering, permits one to classify people as "right-movers" or "left-movers."

What kinds of people glance to the left? Those who are more prone to focus on their internal subjective experiences. "Left-movers" are more readily hypnotizable, more likely to have been classical-humanistic majors in college, and are somewhat more likely to report clear visual imagery. It is significant to our understanding of creativity to note that the more readily hypnotizable person is one whose subjective experiences are rich, who accepts impulses from within, and who is capable of deep imaginative involvements.

Who are the right-movers? They tend to major in science or in "hard," quantitative subjects in college, and they are better at mathematical problems than in verbal ability. They are also quicker to identify concepts when the problem is based on words, as in this problem: "What adjective applies to the nouns—sky, ocean, eyes, jeans?"

What does the direction of a glance tell us about the way the brain functions? It implies a physiological bias—a pre-existing "set." One hemisphere is poised to act a fraction of a second before the other. In a sense, the connections of this half of the brain will take the lead in the person's psychophysiological functioning. When you consciously glance at an apple off to your left, you have an external object to look at, and it is activity within your right frontal lobe that causes your eyes to move to the left. But when there is no external target to look at deliberately, the glance is spontaneous, determined by internal factors. It is plausible to think, then, that when left-movers start their movement of internal reflection, they are revealing the greater facility in function within their right cerebral hemisphere. This bias in favor of the right hemisphere more readily activates the eye-movement system in their right frontal lobe and expresses itself in a quick, unconscious glance to the left.

How significant a glance may be as a clue to basic differences among persons in their temperaments, life-styles, and the way they create can, for the moment, be better imagined than defined, for the basic descriptive work is still going on, and much still needs to be done. Again, we see that an observation raises far more questions than it answers. But in the interim the issues raised illustrate the spectrum of decisions—subjective/objective, humanistic/scientific—that our two hemispheres make every day throughout many levels of creative thought.

A vast chorus of internal dialogue, verbal and non-verbal, embellishes our loosest associations as we dream, or focuses our concentrated attention when we are awake. Communication between the two hemispheres of the brain is essential if our creative efforts are to be well integrated in many dimensions: verbal and visual-spatial; internal and external; past, present, and future. Indeed, when the halves of the brain exchange their disparate experiences, pool their viewpoints and approaches, the resulting synthesis brings to problem solving a whole symphony of talents. The corpus callosum serves as the major thoroughfare rapidly transferring this information. Through it the left hemisphere speaks, quite literally, to the right, and the right hemisphere answers with its own repertoire of musical refrains, *sotto voce*.

Because the frontal, parietal, temporal, occipital, and limbic lobes of the brain are each paired, we begin to see the creative quest as the fusion of a major orchestral performance, with drum beats and clashing cymbals from all the more primitive deeper structures of the brain stem contributing their basic rhythm.

James H. Austin

James H. Austin is with the University of Colorado Medical Center. The above is condensed from a chapter of his forthcoming book, Chase, Chance, and Creativity.

man differences in left-brain, right-brain and the spectrum of variations that genetic inheritance makes possible in brain physiology and *therefore* in temperament and talents—each individual brain is truly unique. The degree and kind of inherent individuality each of us carries around in his brain—in its surface features, its internal fiber organization, microstructure, and chemistry—would probably make those differences seen in facial features or in fingerprint patterns look relatively simple and crude by comparison.

A second message that emerges from the findings on hemispheric specialization is that our educational system and modern society generally (with its very heavy emphasis on communication and on early training in the three Rs) discriminates against one whole half of the brain. I refer, of course, to the non-verbal, non-mathematical minor hemisphere, which, we find, has its own perceptual, mechanical, and spatial mode of apprehension and reasoning. In our present school system, the attention given to the minor hemisphere of the brain is minimal compared with the training lavished on the left, or major, hemisphere.

A third and final message for social change that we get from the world of the laboratory is a complex one that precludes a simple summary. One of the more important things to come out of our brain research in recent years—from my standpoint, at least—is a greatly changed idea of the conscious mind and its relation to brain mechanism. The new interpretation, or reformulation, involves a direct break with long-established materialistic and behavioristic thinking, which has dominated neuroscience for many decades. Instead of dispensing with consciousness as just an "inner aspect" of the brain process, or as some passive "epiphenomenon" or other impotent by-product, as has been the custom, our present interpretation would make the conscious mind an integral part of the brain process itself and an essential constituent of the action. As a dynamic emergent property of cerebral excitation, subjective experience acquires causal potency and becomes a causal determinant in brain function. Although inseparably tied to the material brain process, it is something distinct and special in its own right, "different from and more than" its component physicochemical elements.

Its directive control influence is seen to reside in the universal power of the whole over its parts, in this case the power of high-order cerebral processes over their constituent neurochemical components. On these new terms, consciousness is put to work, given a use, and a reason for being and for having been evolved in a material world. Not only does the brain's physiology determine the mental effects, as has been generally agreed, but now, in addition, the emergent mental operations are conceived in turn to control the component neurophysiology through their higher organizational properties. The scheme provides a conceptual explanatory model for the interaction of mind with matter in terms that do not violate the principles of scientific explanation or those of modern neuroscience.

After more than 50 years of strict behaviorist avoidance of such terms as "mental imagery" and visual, verbal, auditory "images," in the past five years, these terms have come into wide usage as explanatory constructs in the literature on cognition, perception, and other higher functions.

The revised interpretation brings the conscious mind into the causal sequence in human decision making—and therefore into behavior generally—and thus back into the realm of experimental science from which it has long been excluded. This swing in psychology and neuroscience away from hard-core materialism and reductionism toward a new, more acceptable brand of mentalism tends now to restore to the scientific image of human nature some of the dignity, freedom, and other humanistic attributes of which it had been deprived by the behavioristic approach.

Old metaphysical dualisms and the seemingly irreconcilable paradoxes that formerly prevailed between the realities of inner experience on the one hand and those of experimental brain science on the other have become reconciled today in a single comprehensive and unifying view of mind, brain, and man in nature. Within the brain we pass conceptually in a single continuum from the brain's subnuclear particles on up (through atoms and molecules to cells and nerve-circuit systems without consciousness) to cerebral processes with consciousness.

When subjective values are conceived to have objective consequences in the brain, they no longer need be set off in a realm outside the domain of science. The old proposition that science deals with facts, not with values, and its corollary, that value judgments lie outside the realm of science, no longer apply in the new framework. Instead of separating science from values, the present interpretation (when all the various ramifications and logical implications are followed through) leads to a stand in which science becomes the best source, method, and authority for determining ultimate value and those ultimate ethical axioms and guideline beliefs to live and govern by. By the word *science*, I refer broadly to the knowledge, understanding, insight, and perspectives that come from science. But, more particularly, I am thinking of the principles for establishing validity and reliability and credibility of the scientific way as an approach to truth, insofar as the human brain can comprehend truth. □