

Groundbreaking work over
four decades has led to
ongoing insights about brain
organization and consciousness

The Split Brain

By Michael S. Gazzaniga

Revisited

About 35 years ago in *Scientific American*, I wrote about dramatic new studies of the brain.

Three patients who were seeking relief from epilepsy had undergone surgery that severed the corpus callosum—the super-highway of neurons connecting the halves of the brain. By working with these patients, my colleagues Roger W. Sperry, Joseph E. Bogen, P. J. Vogel and I witnessed what happened when the left and the right hemispheres were unable to communicate with each other.

It became clear that visual information no longer moved between the two sides. If we projected an image to the right visual field—that is, to the left hemisphere, which is where information from the right field is processed—the patients could describe what they saw. But when the same image was displayed to the left visual field, the patients drew a blank: they said they didn't see anything. Yet if we asked them to point to an object similar to the one being projected, they could do so with ease. The right brain saw the image and could mobilize a nonverbal response. It simply couldn't talk about what it saw.

The same proved true for touch, smell and sound. Additionally, each half of the brain could control the upper muscles of both arms, but the muscles manipulating hand movement could be orchestrated only by the contralateral hemisphere. In other words, the right hemisphere could control only the left hand and the left hemisphere, only the right hand.

Ultimately, we discovered that the two hemispheres control vastly different aspects of thought and action. Each half has its

own specialization and thus its own limitations and advantages. The left brain is dominant for language and speech. The right excels at visual-motor tasks.

In the intervening decades, split-brain research has continued to illuminate many areas of neuroscience. Not only have we and others learned even more about how the hemispheres differ, but we also have been able to understand how they communicate once they have been separated. Split-brain studies have shed light on language, on mechanisms of perception and attention, and on brain organization as well as the potential seat of false memories. Perhaps most intriguing has been the contribution of these studies to our understanding of consciousness and evolution.

The original split-brain studies raised many interesting questions, including whether the distinct halves could still “talk” to each other and what role this communication played in thought and action. There are several bridges of neurons, called commissures, that connect the hemispheres. The corpus callosum is the largest and typically the one severed during surgery for epilepsy. But what of the many other, smaller commissures?

Remaining Bridges

BY STUDYING THE ATTENTIONAL SYSTEM, researchers have been able to address this question. Attention involves many structures in the cortex and the subcortex—the older, more primitive part of our brains. In the 1980s Jeffrey D. Holtzman of Cornell University Medical College found that each hemisphere is able to direct spatial attention not only to its own sensory sphere but also to certain points in the sensory sphere of the opposite, disconnected hemisphere. This discovery suggests that the attentional system is common to both hemispheres—at least with regard to spatial information—and can still operate via some remaining interhemispheric connections.

BRAIN WIRING is, in many cases, contralateral (left). The right hemisphere processes information from the left visual field, whereas the left hemisphere processes data from the right visual field. For hand movement, the right hemisphere controls the left hand; the left hemisphere controls the right. Both hemispheres dictate upper-arm movement. The two hemispheres are connected by neuronal bridges called commissures. The largest of these, and the one severed during split-brain operations, is the corpus callosum.

Holtzman's work was especially intriguing because it raised the possibility that there were finite attentional "resources." He posited that working on one kind of task uses certain brain resources; the harder the task, the more of these resources are needed—and the more one half of the brain must call on the sub-cortex or the other hemisphere for help. In 1982 Holtzman led the way again, discovering that, indeed, the harder one half of a split brain worked, the harder it was for the other half to carry out another task simultaneously.

Investigations by Steve J. Luck of the University of Iowa, Steven A. Hillyard and his colleagues at the University of California at San Diego and G. Ronald Mangun, now at the Duke University School of Medicine, have shown that another aspect of attention is also preserved in the split brain. They looked at what happens when a person searches a visual field for a pattern or an object. The researchers found that split-brain patients

writing hand, drawing its stimulus—the arrow—on top of the bow. We discovered this chimera by giving less easily integrated word pairs like "sky" and "scraper." The subject did not draw a tall building; instead he drew the sky over a picture of a scraper.

The Limits of Extrapolation

IN ADDITION TO HELPING neuroscientists determine which systems still work and which are severed along with the corpus callosum, studies of communication between the hemispheres led to an important finding about the limits of nonhuman studies. For many years, neuroscientists have examined the brains of monkeys and other creatures to explore the ways in which the human brain operates. Indeed, it has been a common belief that the brains of our closest relatives have an organization and function largely similar, if not identical, to our own.

Split-brain research has shown that this assumption can be

We and others have learned more about how the hemispheres differ and **HOW THEY COMMUNICATE.**

perform better than normal people do in some of these visual-searching tasks. The intact brain appears to inhibit the search mechanisms that each hemisphere naturally possesses.

The left hemisphere, in particular, can exert powerful control over such tasks. Alan Kingstone of the University of British Columbia found that the left hemisphere is "smart" about its search strategies, whereas the right is not. In tests in which a person can deduce how to search efficiently an array of similar items for an odd exception, the left does better than the right. Thus, it seems that the more competent left hemisphere can hijack the intact attentional system.

Although these and other studies indicated that some communication between the split hemispheres remains, other apparent interhemispheric links proved illusory. I conducted an experiment with Kingstone that nearly misled us on this front. We flashed two words to a patient and then asked him to draw what he saw. "Bow" was flashed to one hemisphere and "arrow" to the other. To our surprise, our patient drew a bow and arrow! It appeared that he had internally integrated the information in one hemisphere, which then directed the drawn response [see *illustration on page 30*].

We were wrong. We learned that integration had taken place on the paper, not in the brain. One hemisphere had drawn its item—the bow—and then the other had gained control of the

spurious. Although some structures and functions are remarkably alike, differences abound. The anterior commissure provides one dramatic example. This small structure lies somewhat below the corpus callosum. When this commissure is left intact in otherwise split-brain monkeys, the animals retain the ability to transfer visual information from one hemisphere to the other. People, however, do not transfer visual information in any way. Hence, the same structure carries out different functions in different species.

Even extrapolating between people can be dangerous. One of our first striking findings was that the left brain could freely process language and speak about its experience. Although the right was not so free, we found that it could process some language. Among other skills, the right hemisphere could match words to pictures, do spelling and rhyming, and categorize objects. Although we never found any sophisticated capacity for syntax in that half of the brain, we believed the extent of its lexical knowledge to be quite impressive.

Our first three cases proved to be unusual. Most people's right hemispheres cannot handle even the most rudimentary language, contrary to what we initially observed. This finding is in keeping with other neurological data, particularly those from stroke victims. Damage to the left hemisphere is far more detrimental to language function than is damage to the right.

Nevertheless, there exists a great deal of plasticity and individual variation. One patient, dubbed J.W., developed the capacity to speak out of the right hemisphere—13 years after surgery. J.W. can now occasionally speak about information presented to the left or to the right brain.

Kathleen B. Baynes of the University of California at Davis reports another unique case. A left-handed patient spoke out of her left brain after split-brain surgery—not a surprising finding in itself. But the patient could *write* only out of her right,

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nonspeaking hemisphere. This dissociation confirms the idea that the capacity to write need not be associated with the capacity for phonological representation. Put differently, writing appears to be an independent system, an invention of the human species. It can stand alone and does not need to be part of our inherited spoken language system.

Brain Modules

DESPITE MYRIAD EXCEPTIONS, the bulk of split-brain research has revealed an enormous degree of lateralization, or specialization in each hemisphere. As investigators have struggled to understand how the brain achieves its goals and how it is organized, the lateralization revealed by split-brain studies has figured into what is called the modular model. Research in cognitive science, artificial intelligence, evolutionary psychology and neuroscience has directed attention to the idea that brain and mind are built from discrete units, or modules. These modules carry out specific functions, working in concert to assist the mind's information-processing demands.

Within that modular system, the left hemisphere has proved quite dominant for major cognitive activities, such as problem solving. Split-brain surgery does not seem to affect these functions. It is as if the left hemisphere has no need for the vast computational power of the other half of the brain to carry out high-level activities. The right hemisphere, meanwhile, is severely deficient in difficult problem solving.

Joseph E. LeDoux of New York University and I discovered this quality of the left brain almost 25 years ago. We had asked a simple question: How does the left hemisphere respond to behaviors produced by the silent right brain? Each hemisphere was presented a picture that related to one of four pictures placed in front of the split-brain subject. The left and the right hemispheres easily picked the correct card. The left hand pointed to the right hemisphere's choice and the right hand to the left hemisphere's choice [see illustration at right].

We then asked the left hemisphere, the only one that can talk, why the left hand was pointing to the object. It did not know, because the decision to point was made in the right hemisphere. Yet it quickly made up an explanation. We dubbed this creative, narrative talent the interpreter mechanism.

This fascinating ability has been studied to determine how the left hemisphere interpreter affects memory. Elizabeth A. Phelps, now at New York University, Janet Metcalfe of Columbia University and Margaret Funnell of Dartmouth College found that the two hemispheres differ in their ability to process new data. When presented with new information, people usually remember much of what they experience. When questioned, they also usually claim to remember things that were not truly part of the experience. If split-brain patients are given such tests, the left hemisphere generates many false reports. But the right brain does not; it provides a much more veridical account.

This finding may help researchers determine where and how false memories develop. There are several views about when in the cycle of information processing such memories are laid down. Some researchers suggest they develop early in the cycle,

The Interpreter

OUR PERSONAL NARRATIVES originate in the left hemisphere.

My colleagues and I studied this phenomenon by administering a test. Each hemisphere was shown four small pictures, one of which related to a larger picture also presented to that hemisphere. The patient had to choose the most appropriate small picture.

As seen below, the right hemisphere—that is, the left hand—correctly picked the shovel for the snowstorm; the right hand, controlled by the left hemisphere, correctly picked the chicken to go with the bird's foot. Then we asked the patient why the left hand—or right hemisphere—was pointing to the shovel. Because only the left hemisphere retains the ability to talk, it answered. But because it could not know why the right hemisphere was doing what it was doing, it made up a story about what it could see—namely, the chicken. It said the right hemisphere chose the shovel to clean out a chicken shed. —M.S.G.



that erroneous accounts are actually encoded at the time of the event. Others believe false memories reflect an error in reconstructing past experience: in other words, that people develop a schema about what happened and retrospectively fit untrue events—that are nonetheless consistent with the schema—into their recollection of the original experience.

The left hemisphere exhibits certain characteristics that support the latter view. First, developing such schemata is exactly what the left hemisphere interpreter excels at. Second, Funnell discovered that the left hemisphere has an ability to determine the source of a memory, based on the context or the surrounding events. Her work indicates that the left hemisphere actively

Testing for Synthesis

ABILITY TO SYNTHESIZE information between hemispheres is lost after split-brain surgery, as this experiment shows. One hemisphere of a patient was flashed a card with the word “bow”; the other hemisphere saw “arrow.” Because the patient drew a bow and arrow, my colleagues and I assumed the two hemispheres were still able to communicate with each other—despite the severing of the corpus callosum—and had integrated the words into a meaningful composite.

The next test proved us wrong. We flashed “sky” to one hemisphere and “scraper” to the other. The resulting image revealed that the patient was not synthesizing information: sky atop a comblike scraper was drawn, rather than a tall building. One hemisphere drew what it had seen, then the other drew its word. In the case of bow and arrow, the superposition of the two images misled us because the picture appeared integrated. Finally, we tested to see whether each hemisphere could, on its own, integrate words. We flashed “fire” and then “arm” to the right hemisphere. The left hand drew a rifle rather than an arm on fire, so it was clear that each hemisphere was capable of synthesis.

—M.S.G.

LEFT HEMISPHERE

ARROW

DRAWING

RIGHT HEMISPHERE

BOW



LEFT HEMISPHERE

SCRAPER

DRAWING

RIGHT HEMISPHERE

SKY



LEFT HEMISPHERE



DRAWING

RIGHT HEMISPHERE

FIRE

ARM



places its experiences in a larger context, whereas the right simply attends to the perceptual aspects of the stimulus.

These findings all suggest that the interpretive mechanism of the left hemisphere is always hard at work, seeking the meaning of events. It is constantly looking for order and reason, even when there is none—which leads it continually to make mistakes. It tends to overgeneralize, frequently constructing a potential past as opposed to a true one.

The Evolutionary Perspective

GEORGE L. WOLFORD of Dartmouth has lent even more support to this view of the left hemisphere. In a simple test that requires a person to guess whether a light is going to appear on the top or bottom of a computer screen, humans perform inventively. The experimenter manipulates the stimulus so that the light appears on the top 80 percent of the time but in a random sequence. While it quickly becomes evident that the top button is being illuminated more often, people invariably try to figure out the entire pattern or sequence—and they truly believe they can. Yet by adopting this strategy, they are correct only 68 percent of the time. If they always pressed the top button, they would be correct 80 percent of the time.

But rats and other animals are more likely to “learn to maximize,” pressing only the top button. The right hemisphere acts in the same way: it does not try to interpret its experience and find deeper meaning. It continues to live only in the present—and to be correct 80 percent of the time. But the left, when asked to explain why it is attempting to figure the whole sequence, always comes up with a theory, no matter how outlandish.

This narrative phenomenon is best explained by evolutionary theory. The human brain, like any brain, is a collection of neurological adaptations established through natural selection. These adaptations each have their own representation—that is, they can be lateralized to specific regions or networks in the brain. But throughout the animal kingdom, capacities are generally not lateralized. Instead they tend to be found in both hemispheres to roughly equal degrees. And although monkeys show some signs of lateral specialization, these are rare and inconsistent.

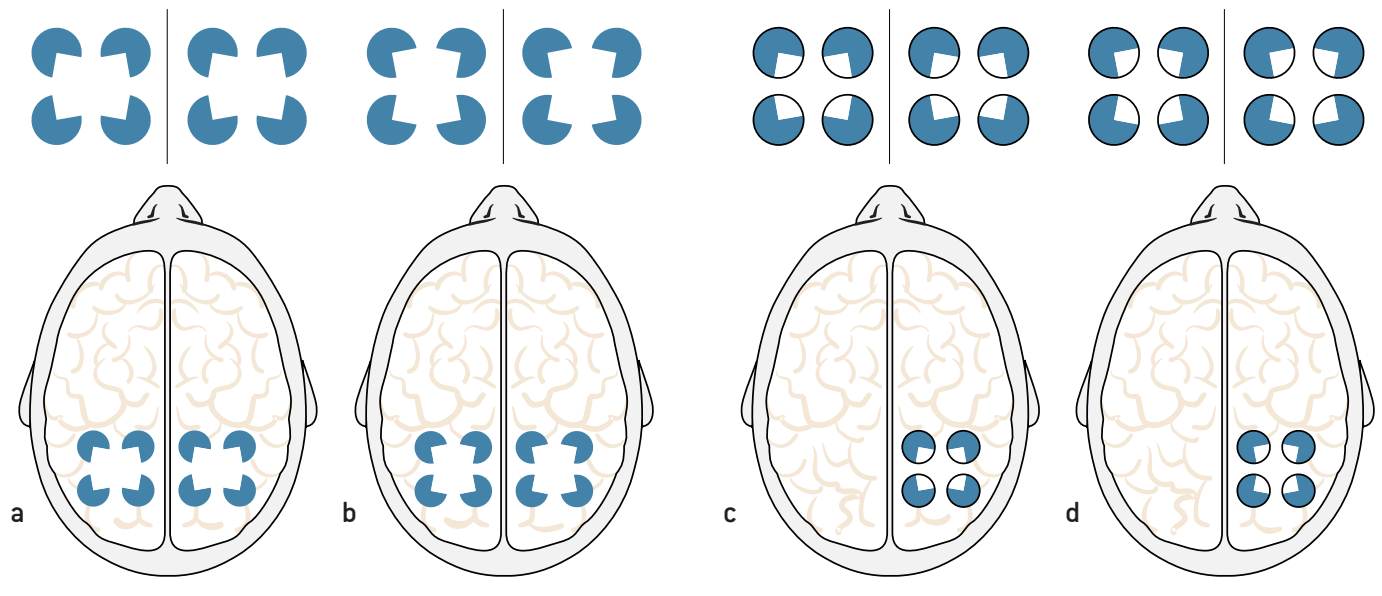
For this reason, it has always appeared that the lateralization seen in the human brain was an evolutionary add-on—mechanisms or abilities that were laid down in one hemisphere only. We recently stumbled across an amazing hemispheric dissociation that challenges this view. It forced us to speculate that some lateralized phenomena may arise from a hemisphere’s losing an ability, not gaining it.

In what must have been fierce competition for cortical space, the evolving primate brain would have been hard-pressed to gain new faculties without losing old ones. Lateralization could have been its salvation. Because the two hemispheres are connected, mutational tinkering with a homologous cortical region could give rise to a new function—yet not cost the animal, because the other side would remain unaffected.

Paul M. Corballis and Robert Fendrich of Dartmouth, Robert M. Shapley of New York University and I studied in many split-brain patients the perception of what are called illusory con-

Looking for Illusions

ILLUSORY CONTOURS REVEAL that the human right brain can process some things that the left cannot. Both hemispheres can “see” whether the illusory rectangles of this experiment are fat (a) or thin (b). But when outlines are added, only the right brain can still tell the difference (c and d). In mice, however, both hemispheres can consistently perceive these differences. For a rodent to perform better than we do suggests that some capabilities were lost from one hemisphere or the other as the human brain evolved. New capabilities may have squeezed out old ones in a race for space. —M.S.G.



tours. Earlier work had suggested that seeing the well-known illusory contours of the late Gaetano Kanizsa of the University of Trieste was the right hemisphere’s specialty. Our experiments revealed a different situation.

We discovered that both hemispheres could perceive illusory contours—but that the right hemisphere was able to grasp certain perceptual groupings that the left could not. Thus, whereas both hemispheres in a split-brain person can judge whether the illusory rectangles are fat or thin when no line is drawn around the openings of, say, “Pacman” figures, only the right can continue to make the judgment after a line has been drawn [see illustration above]. This setup is referred to as the amodal version of the test.

What is so interesting is that Kanizsa himself demonstrated that mice can do the amodal version. That a lowly mouse can perceive perceptual groupings, whereas a human’s left hemisphere cannot, suggests that a capacity has been lost. Could it be that the emergence of a human capacity like language—or an interpretive mechanism—chased this perceptual skill out of the left brain? We think so, and this opinion gives rise to a fresh way of thinking about the origins of lateral specialization.

Our uniquely human skills may well be produced by minute and circumscribed neuronal networks. And yet our highly modularized brain generates the feeling in all of us that we are integrated and unified. How so, given that we are a collection of specialized modules?

The answer may be that the left hemisphere seeks explanations for why events occur. The advantage of such a system is obvious. By going beyond the simple observation of events and

asking why they happened, a brain can cope with these same events better, should they happen again.

Realizing the strengths and weaknesses of each hemisphere prompted us to think about the basis of mind, about this overarching organization. After many years of fascinating research on the split brain, it appears that the inventive and interpreting left hemisphere has a conscious experience very different from that of the truthful, literal right brain. Although both hemispheres can be viewed as conscious, the left brain’s consciousness far surpasses that of the right. Which raises another set of questions that should keep us busy for the next 30 years or so. ■

MORE TO EXPLORE

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