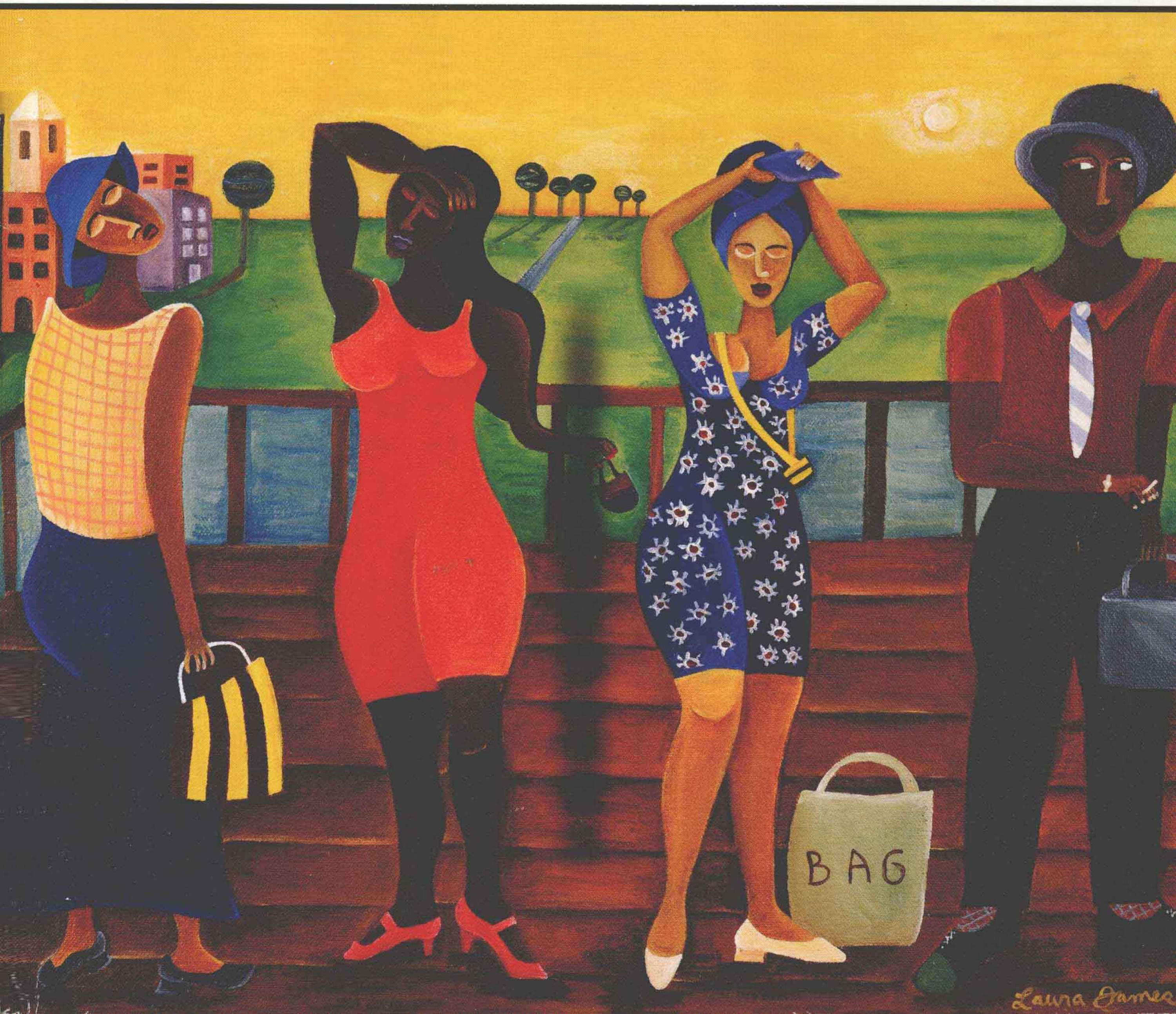
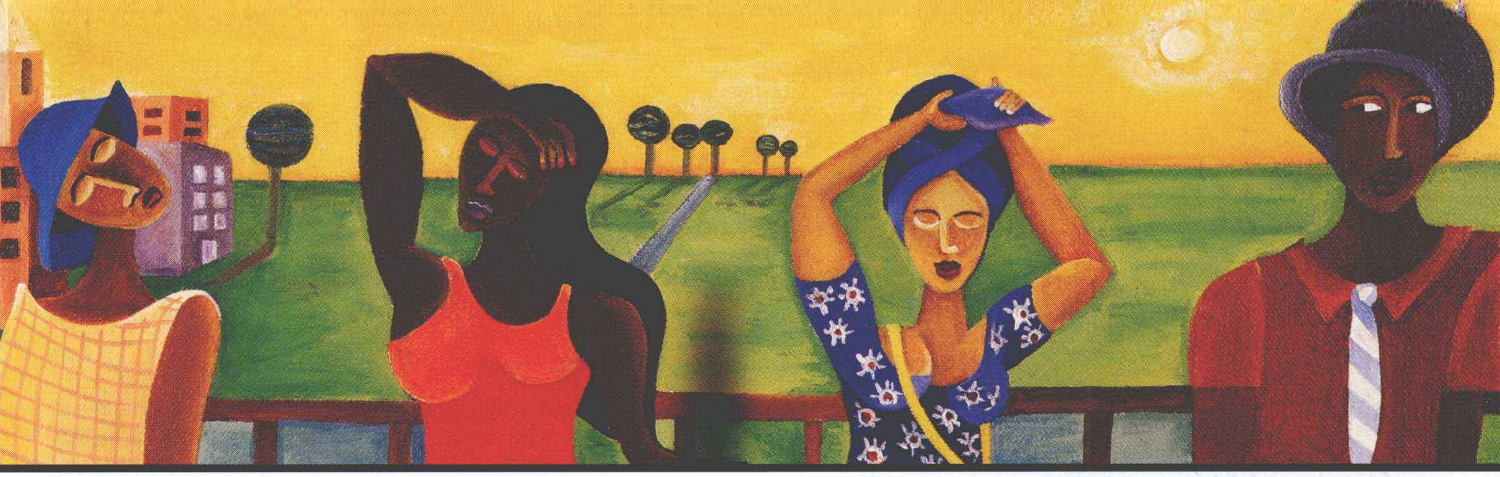
SCIENTIFIC AMERICAN

14 recent articles from SCIENTIFIC AMERICAN magazine selected by David G. Myers

Psychology Reader

to accompany INTRODUCTORY PSYCHOLOGY TEXTS by DAVID G. MYERS





Letter to the Student

IT HAS BEEN BUT A CENTURY AND A SCORE — A MERE EYEBLINK OF TIME to any historian or philosopher — since psychological science began on a December, 1879, day in Wilhelm Wundt's lab. Since that day we have learned that our neural fabric is composed of separate cells that "talk" to one another through chemical messengers, that our brain's two hemispheres serve differing functions, and that we assemble a simple visual perception by an amazingly intricate process that is rather like taking a house apart, splinter by splinter, and reassembling it elsewhere. We have also learned much about the heritability of various traits, about the roots of misery and happiness, and about the remarkable abilities of newborns. We have learned how abilities vary and how they change with age, how we construct memories, how emotions influence health, how we view and affect one another, and how culture and other environmental factors influence us.

Despite this exhilarating progress, our knowledge may, another century and a score from now, seem to our descendants like relative ignorance. Questions remain unanswered, issues unresolved. What molecular genetics contribute to schizophrenia? What are the relative effects of genetic heritage, home environment, and peers on the personalities and values of developing children? To what extent are our judgments and behaviors the product of thinking that is self-controlled and conscious versus automatic and unconscious? What is the function of dreams? How does the material brain give rise to consciousness?

Psychology is less a set of findings than a way of asking and answering such questions. Over the years, this process of asking and answering questions about behavior and the mind has nowhere been better displayed than in the pages of SCIENTIFIC AMERICAN. In this collection from its recent issues, leading scientists — "Magellans of the mind" — show us how they explore and map the mind. How, from ancient history to the present, have humans understood the brain? How does the brain change with age? How does it enable our perceptions of music, our memories, our language, our intelligence, our disorders? How are we influenced by television, by persuasion, and by our abundance of choices?

In each case, we find a detective story, marked by the testing of competing ideas. "Truth is arrived at by the painstaking process of eliminating the untrue," said master detective Sherlock Holmes. What remains — the apparent truth — is sometimes surprising. "Life is infinitely stranger than anything which the mind of man could invent," Sherlock also declared. So read on, looking not only for the answers, but also for the sleuthing. Therein lies the heart of psychology.

David G. Myers
Hope College
davidmyers.org

Contents

2

THE HISTORY OF PSYCHOLOGY

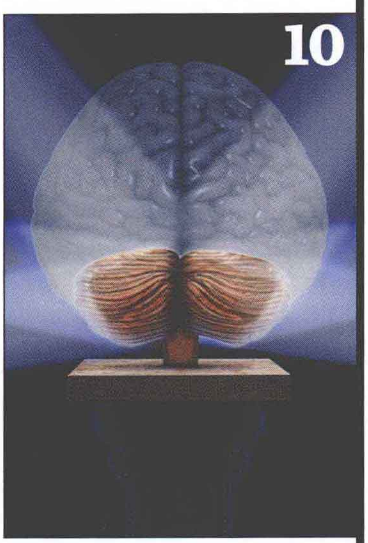
"Humbled by History"
by Robert-Benjamin Illing, SCIENTIFIC AMERICAN: MIND, 2003

The quest to understand the human brain has a long and checkered past. Aristotle believed our human essence resided in the heart, not the brain. From Galen before 200 A.D. to the Middle Ages, many scholars attributed importance to the brain's empty spaces, its ventricles, which they believed contained spiritual energy. More recently scientists came to understand that the brain's functions could be mapped, that neural tissue conducts electricity, and that tiny molecules underlie the brain's internal communication.

DISCUSSION QUESTIONS:

1) "Time and again," notes Illing, "scientists have had to modify or even discard concepts that their predecessors had crafted on careful research." Do you foresee this happening again with today's understanding of the brain?

2) Neuroscientists' ultimate quest is to understand how the physical brain gives rise to consciousness. Do you think this will ever happen, or is consciousness destined forever to be a mystery?



10

NEUROSCIENCE AND BEHAVIOR

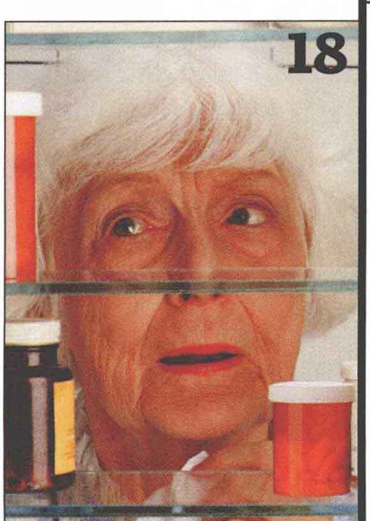
"Rethinking the 'Lesser Brain' "
by James M. Bower and Lawrence M. Parsons, SCIENTIFIC AMERICAN, August 2003

Unlike our "big brain" (the cerebrum), our baseball-sized "little brain" (the cerebellum) gets much less press. But not only does the cerebellum help coordinate our body movements, it also has been discovered to be active as we attend to and perceive the world and plan our behavior. Given the cerebellum's size — its surface of densely packed neurons occupy roughly the same surface area as one hemisphere of the cerebral cortex — its cognitive functions perhaps shouldn't have surprised us.

DISCUSSION QUESTIONS:

1) How much has the cerebellum's circuitry changed across time and species?

2) How have scientists discovered the cerebellum's cognitive functions?



18

THE DEVELOPING PERSON

"Promised Land or Purgatory?"
by Catherine Johnson, SCIENTIFIC AMERICAN: THE SCIENCE OF STAYING YOUNG, 2004

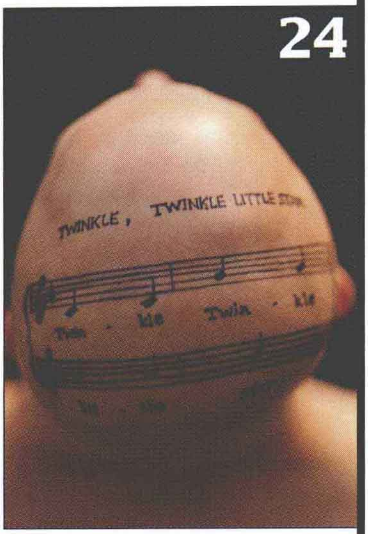
What is it like to grow old? As friends depart, energy subsides, and life's end approaches, do senior citizens despair? On the contrary: as the text explains, four in five people over 65 — a proportion comparable to younger and middle-aged adults — report being "satisfied" with life. Yet Catherine Johnson illustrates that seniors must cope with the challenges of loneliness, arthritis, hearing loss, and other stressors. Nevertheless, many people remain physically and mentally healthy into their eighties and beyond. Geriatric and psychological sciences reveal some of the secrets of successful aging.

DISCUSSION QUESTIONS:

1) What biological changes and what psychological factors put older people at risk for depression?

2) How might older people sustain their mental ability and sense of well-being?

Contents



SENSATION

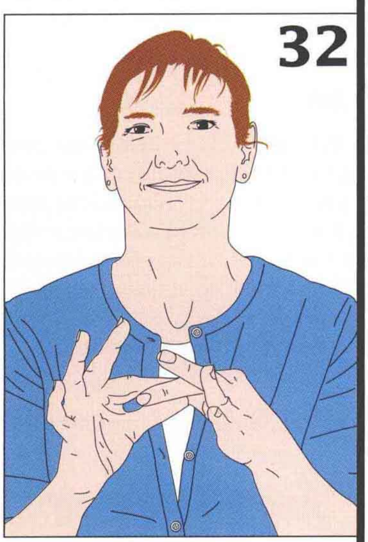
"Music in Your Head"
by Eckart O. Alternmüller, Scientific American: Mind, 2003

Music, which is part of the universal human experience, is an auditory experience that engages the left hemisphere's processing of rhythm, the right hemisphere's processing of pitch and melody, and combines them with the tactile and emotional experiences processed by other brain areas. For experienced listeners, learning also shapes and supplements the music effect.

DISCUSSION QUESTIONS:

1) What areas of the brain process music?

2) How does learning alter our experience of music?



LANGUAGE

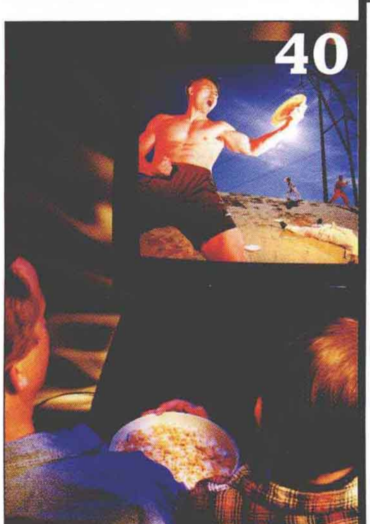
"Sign Language in the Brain"
by Gregory Hickok, Ursula Bellugi, and Edward S. Klima,
Scientific American: The Hidden Mind, 2002

To understand how the brain processes language, some scientists have studied people who hear and speak. But what about people whose language requires seeing and gesture? Gregory Hickok and his colleague explain what leads them to conclude that Deaf signers' and hearing speakers' brains process language similarly. Whether signed or spoken, language processing occurs mostly in the left hemisphere with subfunctions carried out in similar specific areas.

DISCUSSION QUESTIONS:

1) What evidence indicates similarities in how Deaf and hearing people process language?

2) How has brain damage been observed to affect Deaf people's language fluency?



CONSCIOUSNESS

"Television Addiction is No Mere Metaphor"
by Robert Kubey and Mihaly Csikszentmihalyi, Scientific American: Mind, 2003

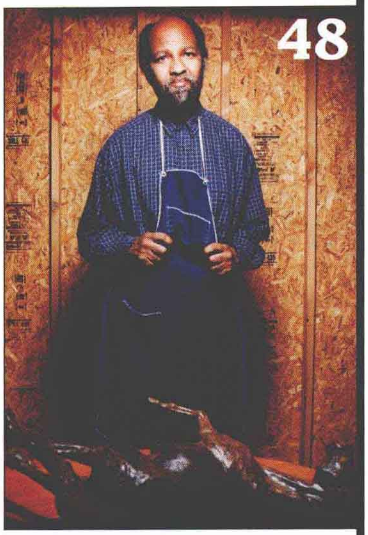
Many television viewers behave like people with substance dependence: they try and fail to reduce use, and may experience the pain of withdrawal when going cold turkey. Television captures and holds our attention with sudden visual cuts, zooms, pans, and noises that harness our native tendency to orient to any sudden or novel stimulus. But when TV interferes with our active engagement in the "flow" of life, our development and well-being may suffer.

DISCUSSION QUESTIONS:

1) Based on the information in this essay and in your text, would you say that heavy, prolonged TV viewing qualifies as an "addiction?"

2) Do you, or people you know, exhibit a dysfunctional dependence on TV watching? If so, what steps might you or they take to kick the habit or to exert more self-control?

Contents

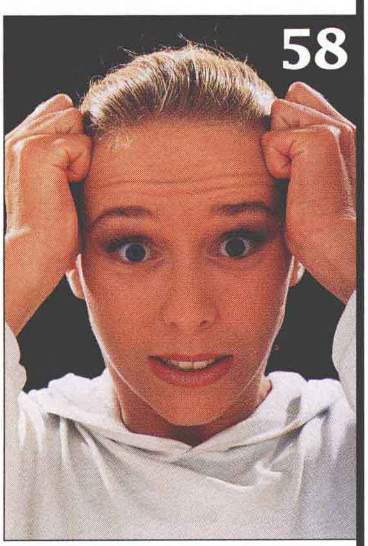


Is intelligence one general ability or several specific abilities? Perhaps, as noted in the text, you have known a talented artist who is dumbfounded by the simplest mathematical problems, or a brilliant math student who has little aptitude for literary discussion. Such anecdotes suggest that there is not only a general intelligence factor, but also what Howard Gardner has called "multiple intelligences." The most striking example of such are people with Savant Syndrome whose artistic brilliance or spectacular memory capacity shines above their developmental disorders. Darold Treffert and Gregory Wallace introduce us to some remarkable cases.

DISCUSSION QUESTIONS:

1) What do people with Savant Syndrome teach us about intelligence?

2) What sorts of special abilities do they exhibit?

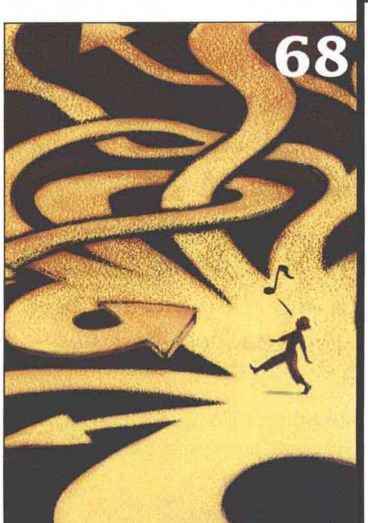


Have you ever noticed that some emotional reactions are instantaneous — before we consciously analyze why we're responding that way to the situation? From his studies of the neural roots of emotion, neuroscientist Joseph LeDoux has an explanation. As I explain in the text, LeDoux's research reveals that some neural pathways bypass areas of the brain associated with conscious thinking. One such pathway runs from the eye or ear to the sensory switchboard, the thalamus, and straight from there to an emotional control center, the amygdala. The amygdala sends more neural projections up to the thinking cortex than it receives back; this makes it easier for our feelings to hijack our thinking than for our thinking to rule our feelings.

DISCUSSION QUESTIONS:

1) What sorts of experiments enabled LeDoux to show that fear conditioning can occur without involving the cortex?

2) What is the adaptive or survival value of a quick, short circuit emotional response system?



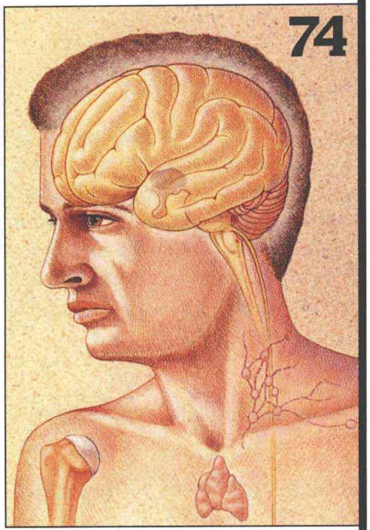
Freedom makes for happiness, we suppose. What the text calls an "internal locus of control" contributes to achievement and well-being. So more choices should make for more happiness, right? Not so, contends Barry Schwartz. An excessive number of choices can breed rumination over the alternatives, regret over things not chosen, and lessened satisfaction and happiness when results fall short of high expectations. Choice is good, up to a point, beyond which the costs of more choices outweigh the benefits.

DISCUSSION QUESTIONS:

1) Do you tend to be more of what Schwartz terms a "maximizer" or a "satisficer?"

2) What things might you do, when facing choices, to increase your eventual satisfaction?

Contents

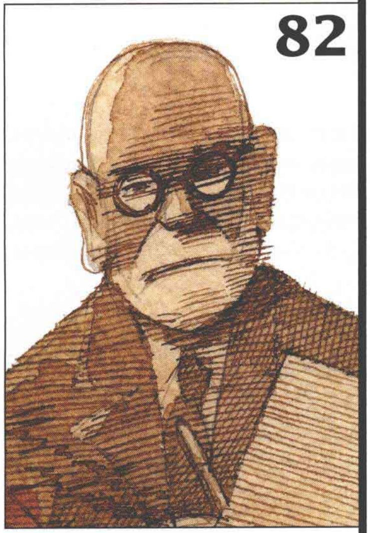


The brain and the immune system, it's now clear, have a continuous conversation. "Chemicals released by nerve cells can act as signals to immune cells," explain Esther Sternberg and Philip Gold. And that conversation helps us understand how the mind influences our health and vulnerability to disease, and how stress-related hormones also affect our mental and emotional state.

DISCUSSION QUESTIONS:

1) How does the stress response system affect the body's disease-fighting immune system?

2) What explains the interplay between the brain, the immune system, and moods?

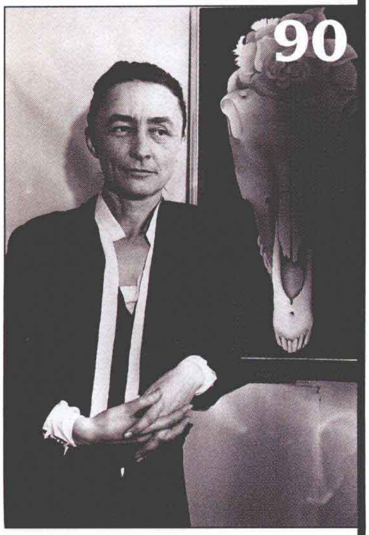


Although many of Freud's ideas have been discounted by contemporary science, neuropsychologist Mark Solms contends that Freud's understanding of the scale and power of the unconscious mind is finding confirmation. Moreover, the discovery of brain systems that underlie pleasure and reward, restraint and inhibition, help "finish the job" that Freud began, says Solms. J. Allan Hobson, a researcher of sleep and dreams, argues that the connection between Freud's theories and today's neuroscience is so far-fetched that we had best "start over and create a neurocognitive model of the mind."

DISCUSSION QUESTIONS:

1) In response to criticisms of Freud's ideas, summarized in the text, Solms affirms some of Freud's core ideas. Hobson, on the other hand, thinks "psychoanalysis is in big trouble." In your view, how strong a case does each make?

2) Which of Freud's ideas seem to be surviving, and which seem to be dying out?



Depression, as the text indicates, is the "common cold" of psychological disorders — the most frequent reason that people seek mental health services. Psychiatry professor Kay Redfield Jamison has studied one particularly depression-prone group: gifted artists, musicians, and writers. More than others, they are vulnerable to the roller coaster emotions of bipolar disorder.

DISCUSSION QUESTIONS

1) How might the depths of depression and the energy of mania both contribute to creative achievement?

2) Although few of us suffer the extreme mood swings of bipolar disorder, we all have our downs and ups. Would your own life be better if you could live on a flat emotional plateau? Or have you benefited from, and are you in some sense glad for, your own emotional swings?

Contents

What underlies the confused and illogical thinking, and the alien voices or paranoia, that mark the lives of so many with schizophrenia? The text describes the role of one neurotransmitter, dopamine: the brains of some people with schizophrenia have excess receptors for dopamine, and dopamine-blocking drugs often reduce their symptoms. Daniel Javitt and Joseph Coyle describe another culprit: the neurotransmitter glutamate. When its activity is reduced, because of fewer or blocked glutamate receptors, schizophrenia symptoms may appear. Such findings suggest the possibility of new drugs that may more effectively treat schizophrenia.

DISCUSSION QUESTIONS:

1) Why do Javitt and Coyle regard the "dopamine theory" as an incomplete explanation of schizophrenia?

2) What factors might explain why some people suffer abnormal supplies of certain neurotransmitters or their receptors, with resulting schizophrenia?

Drawing on both his social psychological research and his infiltration of sales and fund raising organizations, Robert Cialdini has identified six "weapons of influence." By harnessing some combination of these six persuasion principles — reciprocation, consistency, social validation, liking, authority, and scarcity — people may persuade others to buy, deal, vote, or give. And by our awareness of these persuasion tactics, we stay mindful and self-directed when someone is using them on us.

DISCUSSION QUESTIONS:

1) From your own observation and experience, what are some examples of these persuasion principles?

2) How might you use these principles for positive persuasion? When is the application of these persuasion tactics ethical and appropriate, and when is it unethical and inappropriate?

SCIENTIFIC AMERICAN

Humbled BY HISTORY

Over the centuries, many "proven" ideas about the brain were later found lacking, a lesson worth remembering today

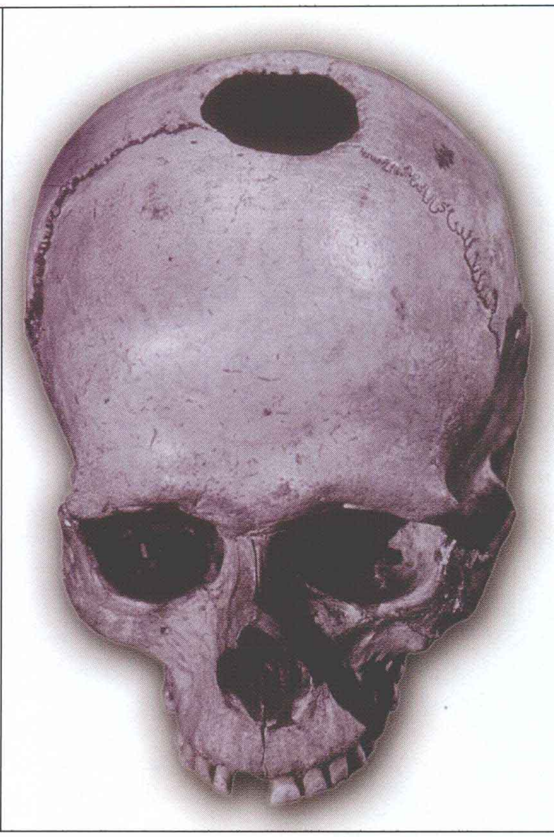
By Robert-Benjamin Illing

What could have motivated the first *Homo sapiens* to explore the inner life of his head? Incredibly, the earliest evidence we have of such interest reaches back 7,000 years, to skulls from Early Stone Age graves that exhibit carefully cut, man-made holes. These so-called trepanations were performed by various cultures around the world, right up to modern times, and many of the subjects must have survived for years, because their skulls show that scar tissue had formed around the holes.

Ancient cultures presumably practiced trepanation to liberate the soul from the evil spirits that were supposedly responsible for everything from fainting spells to bouts of hysteria. But despite those inquisitions, the philosophers and physicians of old seem to have placed far less importance on the brain and nervous system than on other organs. Both the Bible and the Talmud tell of authentic medical observations, but neither provides a single indi-

***The Stone Cutting,* by Hieronymus Bosch (circa 1480), depicts a prevalent medieval operation in which a physician removed a "stone of folly" believed to cause mental illness. The words, roughly translated, say: "Master, cut the stone away, I am a simple man."**

AKG IMAGES/ERICH LESSING



AKG IMAGES

A crater was cut into this human skull from the Mesolithic period, found in Stengnav (Denmark), while its owner was still alive. The edges of the hole have completely healed, which proves that the person survived the operation by years. Such trepanations—attempts to release evil spirits causing illness—were performed up through modern times.

cation that any disease was connected to the brain, spinal cord or nerves. The embalmers of Egyptian pharaohs and high priests prepared the liver and heart with great care but removed the brain through the nose and ears using rods and spoons.

As biblical times gave way to the Middle Ages, the Renaissance and our own modern era, more anatomists, physicians and scientists worked hard to understand the complexities of the brain and mind. Yet time and again they had to modify or even discard concepts that their predecessors had formulated after considerable observation and experiment, concepts that once seemed valuable. It is intriguing to wonder which of today's neurological and psychological precepts we may yet have to put aside as we continue to learn more.

In ancient Egypt and Greece, the heart was the most important organ. Greek philosopher Aristotle (384–322 B.C.) noted that an injury to the heart meant immediate death, whereas head injuries usually brought far less serious consequences and could even heal. He observed, too, that one's heartbeat changed with one's emotional state and that the brain seemed to be without sensation, for touching the brain of a living animal evoked no response. The action of the heart, he concluded, seemed to correspond with life itself. The soul—the independent force driving that life—most likely resided in the liver.

Unlike Aristotle, Pythagoras (circa 570–496 B.C.) and Hippocrates (circa 460–370 B.C.) both had considered the brain to be the "noblest" part of the body. Plato (427–347 B.C.) shared this point of view. He assigned the lower passions such as lust and greed to the liver and the higher ones such as pride, courage, anger and fear to the heart. For reason, it was the brain.

Galen, the anatomist who lived in Alexandria in about A.D. 130–200, was the first to investigate the brain in earnest. He observed that people who suffered strokes could lose certain senses even though their sensory organs remained intact, inferring that the brain was central to sensation. Galen was especially impressed when he studied the brain's ventricles—the empty spaces—which he believed contained something resembling air. In his experiments, when he pressed on the rear ventricle of the exposed brain of a living animal, the animal fell into a deep numbness. If he cut into the ventricle, the animal would not emerge from this trance. If he made only a slight incision into the ventricle surface, the animal would blink its eyes.

(Descartes explained that vapors flowed from sensory nerves into the brain's empty spaces, where decisions of the soul pushed them ahead.)

Galen also believed there was a special connection between these empty spaces and the soul; after all, the gaseous substance they contained, being ethereal, seemed closer to the soul than brain tissue did. The content of the ventricles was inhaled from the cosmos and served as intermediary between body and soul. He christened the vapors of the ventricles *spiritus animalis*—the "animating spirit"—a concept taken as truth for centuries to come.

A Gentle Breeze

It was a long time before subsequent researchers added to Galen's teachings. In the Middle Ages, people called the ventricles "chambers" and began to assign other functions to them. Like the water in a Roman fountain, the *spiritus animalis* flowed through the ventricles and thereby changed its qualities. This belief was the first timid attempt to create a model of brain function.

During the Renaissance, Leonardo da Vinci (1452–1519) and Michelangelo (1475–1564) sought to learn more about the body by looking inside it. Da Vinci drew the first realistic images showing the brain's ventricles [*see illustration below*]. Flemish anatomist Andreas Vesalius (1514–1564) held celebrated dissections in front of large audiences, carefully preparing and depicting the brain. But no one speculated on how the organ functioned.

This reluctance created an opportunity for René Descartes (1596–1650). The French mathematician and philosopher explained that the visible structures of the brain had nothing to do with its mode of functioning. Influenced by his contemporary, Galileo Galilei (1564–1642), Descartes worked from a mechanistic foundation and transformed the character of brain research. He imagined the *spiritus animalis* as a gentle breeze that flowed from the sensory nerves into the ventricles and then to the brain's central organ, the pineal gland. There the machinelike body—the *res extensa*—encountered the independent, immaterial soul—the *res cogitans*. The decisions of the soul, he maintained, generated impulses that moved through the pineal gland and ventricles, causing the *spiritus animalis* to course through the correct motor nerves to the muscles. Tiny filament valves within the nerve tubes controlled the flow.

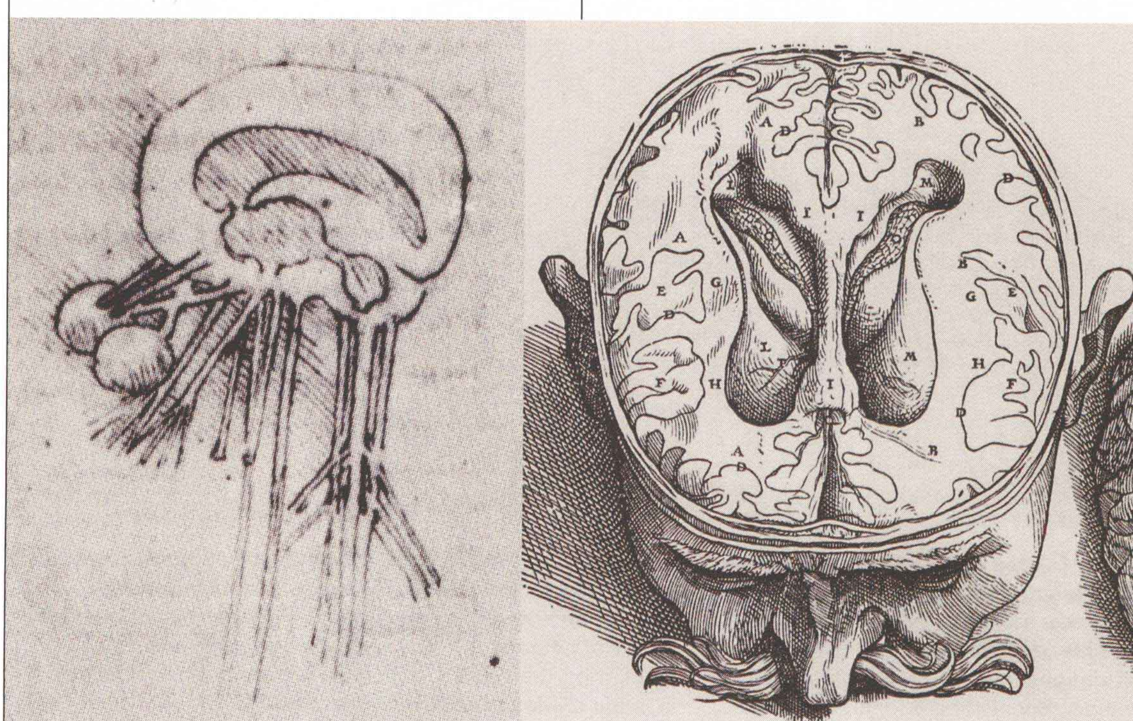
Descartes realized that any mechanical system that could control the vast array of sensory and motor events had to be extremely complex. So he devised a new model: a pipe organ. Its air channels corresponded to the heart and arteries, which via the bloodstream carried the *spiritus animalis* to the ventricles. Like organ stops that determined airflow, valves in the nerves helped the *spiritus animalis* flow into the right "pipes." The music was our reasonable and coordinated behavior.

Descartes's theory was so mechanistic that it could be experimentally verified. Italian physician Giovanni Borelli (1608–1679) held a living animal underwater so that it strove with all its power not to drown. According to the theory, *spiritus animalis* ought to have streamed into its muscles. After a few seconds, he cut into a muscle. Because no bubbles rose into the water, he decided that the animating spirit must be watery rather than gaseous—a *succus nerveus* (nerve juice).

Other physicians, anatomists and physicists, including Isaac Newton, conducted experiments to determine how the brain functioned, but their observations produced contradictory results. By the middle of the 18th century a general malaise had spread about knowledge of the brain and nervous system. Could anyone explain how they functioned, even in principle?

Frogs and Sciatic Nerves

New inspiration came from an unlikely place. Everyone inside laboratories and elsewhere was talking about electricity. Some suggested that it was the medium that flowed through the nerves.



The first anatomically correct representations of the ventricles came from Leonardo da Vinci, whose side view (*left*, circa 1504) shows both the eyeballs and the nerves leading to the brain, and from Andreas Vesalius, who rendered a top view in 1543.

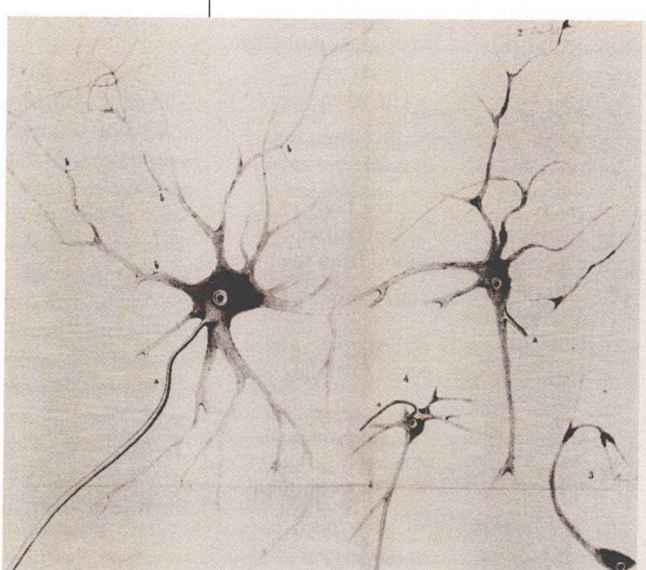
But skeptics noted that nerves seemed to lack insulation. If there was a source of electricity within the body, then the current ought to spread in every direction.

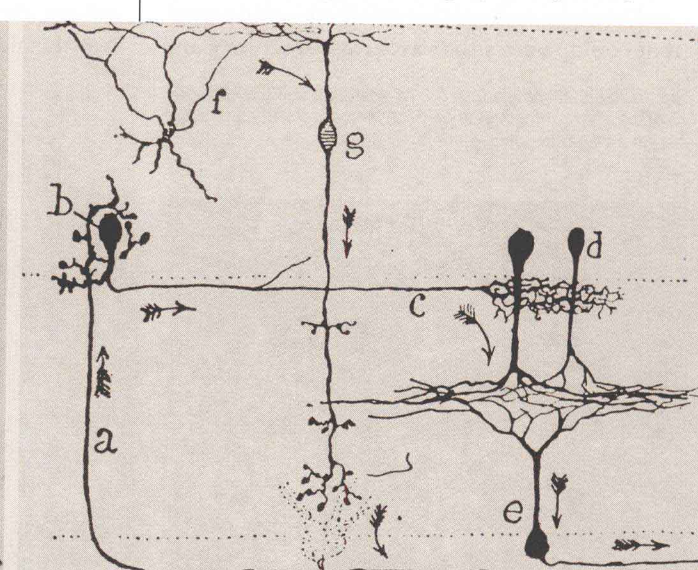
The discussion gained considerable momentum from Italian physician Luigi Galvani (1737–1798). In legendary experiments, he connected a zinc strip to the sciatic nerve of dissected frog legs, then attached the strip with a silver buckle to the muscle. At the moment the circuit was closed and a current flowed, the muscle twitched. The proof that nerves could be stimulated electrically did not, however, prove that electricity and the *spiritus animalis* were identical. It was not until 1843 that German physiologist Emil Du Bois-Reymond (1818–1896) described a current that flowed along a nerve fiber after it was electrically stimulated. When he discovered in 1849 that the same current flowed after chemical stimulation, too, there was finally evidence that the nerves were not passive conductors but producers of electricity.

The question of what nerves were actually made of, however, could not be investigated with the tools available at the time. Throughout the latter 19th century the optics in microscopes were improved, and advances were made in preparing tissue samples for microscopy. Spanish histologist Santiago Ramón y Cajal (1852–1934) noticed that in brain tissue that had been stained, certain cell shapes appeared again and again. He went on to determine that at the end of stained axons there were often special thickenings, so-called terminal buttons. This observation caused him to posit that there was no continuous nerve network, as was believed; instead each neuron was an isolated cell with precisely defined boundaries. In 1906 he shared the Nobel Prize with Camillo Golgi of Italy for their work on the structure of the nervous system. Thus, neuronal theory was born.

Thinking Cells

But how did impulses jump from neuron to neuron? In 1900 Charles Sherrington became the first to demonstrate the existence of inhibitory nerve cells that could turn signals on and off. The English neurophysiologist compared the brain to a telegraph station that sent pulsed messages from point to point. Three years earlier he had already labeled the contact points between neurons "synapses," which literally means "connections." Yet this still did not answer how an impulse could cross a gap. English physiologist John Langley conducted experiments in which he applied nicotine to isolated frog muscles, theorizing that stimulated nerve fibers released a nicotinelike substance at the synapse. But it was German-American chemist and pharmacologist Otto Loewi who finally delivered the experimental proof that a stimulated nerve cell does in fact secrete a substance. His English colleague, Henry Dale, dis-





Depictions by German physician Otto Deiters of isolated nerve cells from the spinal cord of an ox (*left*) were the first to distinguish between dendrites and axons. He published them before his untimely death at age 29 in his 1865 book *Investigations on the Brain and Spinal Cord of Man and the Mammals.* Spanish histologist Santiago Ramón y Cajal was among the earliest to propose that signals travel from neuron to neuron; in one drawing (*right*), he showed the movement of messages via various types of neurons in the retina of a bird, with arrows indicating their directions (from *Histology of the Nervous System of Man and Vertebrates,* 1904).

(Functionalism Refuted?)

A basic tenet of functionalism is that brains and computers are interchangeable. But mathematician and theoretical physicist Roger Penrose of the University of Oxford has used the following thought experiment to shake the theory at its foundation.

All conceivable computers are, in principle, Turing machines (named after English mathematician Alan Turing, who first described them). They carry out sequential operations following definite rules. Turing machines can represent any arbitrary, formal system—one in which each element and each operation is uniquely defined. If the Turing machine is a model for the brain, then brain function is a formal system.

Now consider Austrian-born mathematician Kurt Gödel's incompleteness theorem, or theory of improvability. According to the theorem, in any formal system there are mathematical axioms that are true but that cannot be proved true within the system. Yet if our thoughts constitute a formal system, then we should not be able to recognize the validity of the Gödel axiom. Penrose concluded from this that human capacities of understanding cannot be enclosed within a formal system; the brain is not a Turing machine, and thus the presupposition of functionalism is false. *—R.-B.I.*

covered that this substance was acetylcholine.

In parallel, the first recording of an impulse inside a nerve cell—today called an action potential—was made in 1939 by Alan Hodgkin and Andrew Huxley, two English biophysicists. The action potential proved to be the universal signaling mechanism in nerve cells throughout the animal kingdom.

Nevertheless, neuroscientists were slow to embrace the idea of a chemical transmission of nerve impulses until biophysicist Bernhard Katz of University College London and his colleagues showed in the early 1950s that nerve endings secreted signal substances he called neurotransmitters. The molecules were secreted in "packets" depending on the neurons' electrical activity. Finally, in 1977 in the U.S., cell biologists John Heuser and Thomas Reese demonstrated that vesicles in a neuron's cell membrane gave up their contents of neurotransmitters when hit by an incoming action potential. Whether the "sending cell" or the "receiving cell" would be excited or inhibited depended on the neurotransmitter released and the receptor on the membrane to which it bound.

The discovery of excitatory and inhibitory synapses fed speculation that the nervous system processed information according to fixed procedures. But Canadian psychologist Donald O. Hebb had ventured in 1949 that the communication between nerve cells could change depending on the cells' patterns of activity. In recent decades, his suppositions have been experimentally confirmed many times. The intensity of communication between two neurons can be modified by experience. Nerve cells can learn.

That conclusion had enormous implications for theories of how we *Homo sapiens* think. For centuries, the world's scientists had failed to correlate how the brain's parts functioned with how the mind created thought. Even in the Renaissance it had become clear from observations of diseased and injured people that a person's thinking is inseparable from his or her brain. But what exactly made this organ work? Was it the peculiarities of its neurons, how they were organized, or how they "talked" to one another?

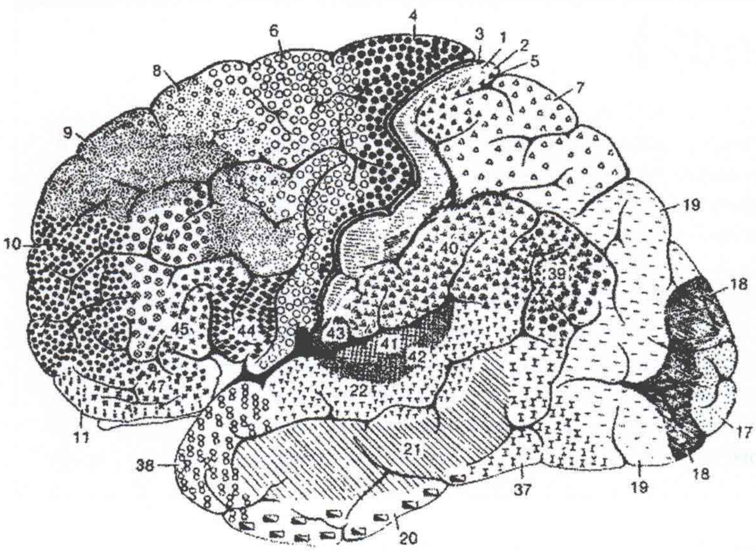
Thomas Willis (1621–1675) had made the first attempts to tie various regions of the brain to specific functions. In his influential work the English doctor declared that the convolutions of the cerebral cortex were the seat of memory and that the white matter within the cerebrum was the seat of the imagination. An area in the interior of the cerebrum—the corpus striatum—was responsible for sensation and motion. Swedish anatomist Emanuel Swedenborg (1688–1772) added that even the outwardly unvarying cerebral cortex must consist of regions with different functions. Otherwise, how could we keep the various aspects of our thoughts separate?

To Map the Brain

The first experimental maps of brain function did not come along until two anatomists in 19th-century Berlin—Eduard Hitzig and Gustav Theodor Fritsch—carefully stimulated the cerebral cortex of cats. Electrically stimulating the rear two thirds of the cortex caused no physical reaction. Stimulating each side of the frontal lobe, however, led to movements of specific limbs. By reducing the current, the researchers could get specific groups of muscles in a given limb to contract. Meanwhile French country doctor Marc Dax documented that aphasics—people who had lost the ability to speak—had often suffered injuries to a distinct

(The Author)

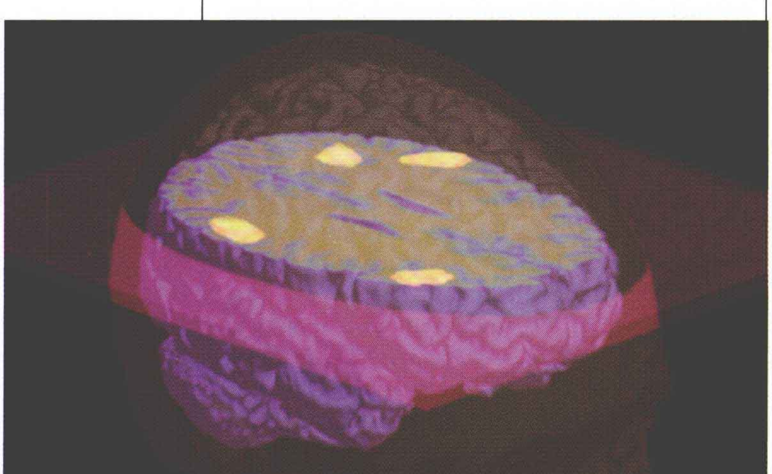
ROBERT-BENJAMIN ILLING is professor of neurobiology and biophysics at the University Clinic in Freiburg, Germany.



In 1909 German anatomist and neurologist Korbinian Brodmann created one of the first maps of the human cerebral cortex (*side view, with forebrain at left*). The numbered regions differed in their tissue architecture, he maintained, because of the structure of the neural nets they contained.

area in the brain's left hemisphere, the Broca region.

American neurosurgeon Wilder Penfield took a major step forward in the 1940s by working with patients in Canada who had to undergo brain surgery. To better orient himself during an operation, he wanted to determine the functions of different regions of the brain. He electrically stimulated various positions on the cortex of conscious patients and noted their sensory perceptions. People reported seeing simple flashes of light or hearing indefinable noises. Sometimes one of their muscles or fingers would contract.



Today's brain maps are based on imaging of neural activity. In 1997 Jonathan D. Cohen of Carnegie Mellon University used functional magnetic resonance imaging to show that four areas in the frontal and parietal regions were highly active in people who tried to remember increasingly longer sequences of letters—a test of working memory.

Occasionally, though, when Penfield stimulated parts of the temple, a patient reported complex, remembered images. One woman said: "I think I heard a mother calling out to her small children. I believe that happened several years ago. It was someone in the neighborhood where I lived." When Penfield stimulated a different spot, the woman said: "Yes. I heard voices, from someplace downstream—a male voice and a female voice. I believe I have seen the river."

Experiments such as these led to maps of the cortex's functions, which have been steadily refined. With them, scientists began to imagine a flow of information through the nervous system. They conceived of the brain as a machine, one that receives, processes and reacts to signals and to stored memories of them. Cybernetics—the science of the regulation of machines and organisms—provided the first theoretical foundation for these ideas. Founded in the 1940s by American mathematician Norbert Wiener, this discipline prompted researchers to adopt a new model for the brain: the calculating machine or the computer, which was just emerging.

The Person as Black Box

Another mathematician in the U.S., John von Neumann, saw action potentials as digital signals, and he demonstrated that any machine with reasonably complex behavior had to incorporate data storage or a memory. Theoretical scientists working with American artificial-intelligence pioneer Warren McCulloch showed that a group of neurons could indeed carry out logical operations, similar to a calculator. And in 1960 German professor Karl Steinbuch of Karlsruhe University developed an artificial associative memory—the first so-called neural net, or learning matrix, a system for storing information in the pattern of connections between digital processing elements.

Right or wrong—and this remains a lively debate today—the computer model is fruitful. Information processing is not tied to any particular component but merely to the logical connections among them, whether they are neurons or transistors. As a result, by the mid-20th century the computer model of the brain began to influence the blossoming science of behavior and experience: psychology.

Even in antiquity, the basic rules of human behavior were understood, but scholars described their origins in metaphysical terms. In the late 19th century these views shifted. German physiologist Wilhelm Wundt started to develop a science of the mind—psychology—using the methods of the nat-

JONATHAN D. COHEN AND LEIGH NYSTROM *Center for the Study of Brain, Mind and Behavior, Princeton University (bottom)* ural sciences. He wanted to distinguish his discipline from metaphysics on the one hand and from physicalism on the other and therefore did not speak of the soul but rather of consciousness.

American psychologists such as William James and John B. Watson, however, concerned themselves almost entirely with the visible and measurable behaviors of an organism and considered mental processes and consciousness to be negligible in importance. To representatives of this "behavioral" school, people and animals were black boxes that reacted to external stimuli—and behaviorists made no effort to look inside. Yet they increasingly ran into trouble trying to explain complex learned behaviors, especially the way in which humans learned language.

At the same time, computers steadily demonstrated abilities that previously were limited to humans; for example, they became serious opponents in chess. But these achievements came from precisely tailored programs. The new challenge was to see if human intelligence could be rooted in mental programs that carried out logical operations.

This line of inquiry brought up two new ideas that would characterize brain and mind research through today. First, understanding computers would be an important step to comprehending the brain. Second, perhaps thinking, feeling and consciousness were not tied to the brain's substance but were brought about through the logical connections of its elements and could thus be emulated in a computer.

These two ideas became the cornerstones of functionalism, which could be described as the basic doctrine of modern cognitive science. Scientists had compared the brain to a fountain or a pipe organ, even though it was obvious that the brain was not really either of these. But according to functionalism, the brain was not just similar to a computer, it *was* a computer. The inverse must also be true: it must be possible to construct a complete brain from a computer, furnish it with a body, and therefore create a lifelike robot.

These notions led certain researchers to paint a bright picture of things to come. For instance, when M.I.T. computer scientist Marvin Minsky was asked by reporters in the 1990s if someday robots might rule the world, he answered: "Yes, but we must not fear this vision, for we ourselves will be these robots. If we, with the help of nanotechnology, create replacement parts for our bodies and brains, we will live longer, possess greater wisdom, and enjoy abilities beyond what we can imagine."

Realism or Science Fiction?

Modern imaging techniques are helping researchers look into the brains of conscious subjects as they act, to determine just how mechanistic or ethereal our brains may be. So far it appears that certain perceptions, mental impulses and sensory processing such as seeing and speaking are accompanied by neural activity in very precise regions of the brain—bringing us back to the ideas of localized brain function and brain mapping, which had been fading into the background.

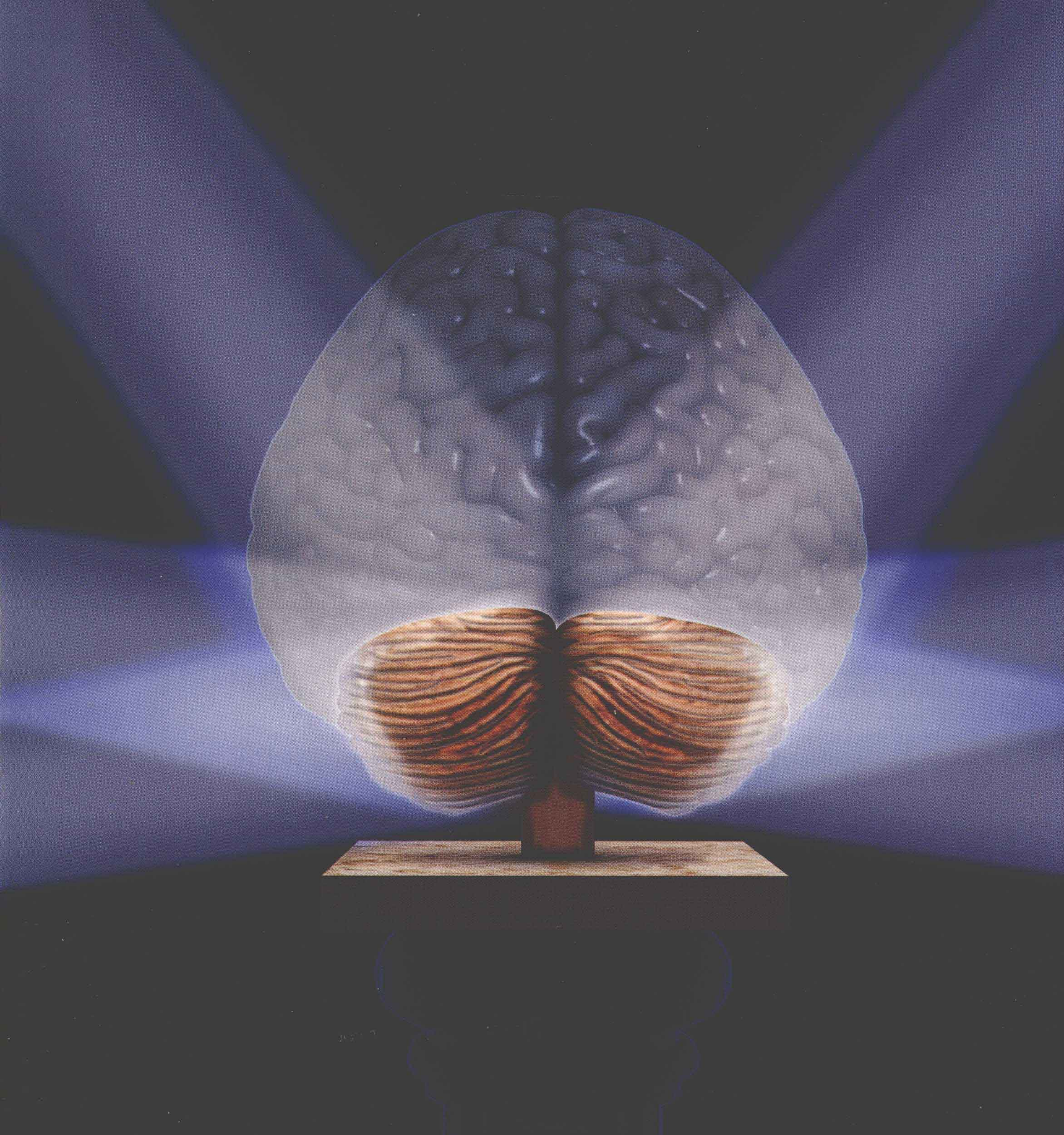
> **(Almost all the models for neural function are based on 19th-century physics. Why? Perhaps the real clues lie in quantum chemistry.)**

Such new research has once again put the question of the relationship between body and soul, and thus between brain and consciousness, at center stage. But it is precisely here that functionalism plays no role. The computer is therefore at best an appropriate metaphor for only some aspects of brain function.

Indeed, there is a red thread running through the history of brain research: time and again scientists have had to modify or even discard concepts that their predecessors had crafted on careful research, ideas they had embraced as underpinnings of their own explorations. For the past several decades, neurobiology has moved deep into the realm of molecules and their chemical reactions. But almost all the proposed molecular models for nerve function lie in the conceptual world of classical physics. Why should the brain's operation be explainable by 19th-century science? Perhaps the real clues lie in quantum mechanics and quantum chemistry, and perhaps these pursuits will invade neurobiology. A look at history forces us to ask: Which of the models in use today will have to make room for new ones?

(Further Reading)

- **Foundations of the Neuron Doctrine.** Gordon M. Shepherd. Oxford University Press, 1991.
- **Origins of Neuroscience.** Stanley Finger. Oxford University Press, 1994.



Long thought to be solely
the BRAIN'S COORDINATOR of body movement,
THE CEREBELLUM is now known to be active during
a wide variety of cognitive and perceptual activities