

SCIENTIFIC AMERICAN **MIND**

THOUGHT • IDEAS • BRAIN SCIENCE

SPECIAL EDITION

The Brain: **A LOOK INSIDE**

- » The Puzzle of
CONSCIOUSNESS
- » Rain Man's
SPECIAL GENIUS
- » Music's Weird Power
- » Why We're
HOOKED ON TV
- » Erasing Fears
- » 6 Tricks of
PERSUASIVE PEOPLE

SCIENTIFIC AMERICAN®

Established 1845

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A Symphony of the Self

Early natural philosophers speculated that our brains contained a homunculus, a kernel of self-awareness: not unlike the soul that was the irreducible core of our self. This “little person” peered out through our eyes and listened through our ears and somehow made sense of the universe. Neuroscientists ejected the homunculus from our heads, however. The circuitry of our brains does not all converge on one point where the essence of ourselves can sit and ruminate.

Instead whatever makes us *us* emerges from countless overlapping neural processes, in the same way that a symphony emerges from the playing of an orchestra’s musical instruments. One can analyze the instruments and the techniques of the musicians or watch the conductor or even read the musical score, but the actual music cannot be found anywhere until the performance begins.

Studying how the mind and brain work sounds like it ought to be about as futile as trying to grab handfuls of air. Yet psychology, neuroscience and related fields have made amazing progress. This special issue introducing *Scientific American Mind* reviews just a sliver of the discoveries that investigators from around the globe have made about the workings of our inner lives.

The breadth of subjects tracks the vastness of thought. Several of our authors grapple with supremely tough questions: How does the gray matter in our skulls give rise to self-awareness? How can we have free will if our brains are bound by predictable mechanisms? How does memory work? Other articles describe how new genetic and biochemical findings elucidate causes of mental illness but also pose ethical quandaries. They illuminate mysteries of sensory perception. They explore how understanding of mental function can help us deal with mundane issues, such as solving problems creatively or making our arguments more persuasive. And a few celebrate the strange, unexpected beauties of the human condition.

Everyone who contributed to *Scientific American Mind* hopes that you’ll find the result as provocative and stimulating as we do. And if it inspires you to any insights into the elusive human psyche, let us know.

John Rennie
 Editor in Chief
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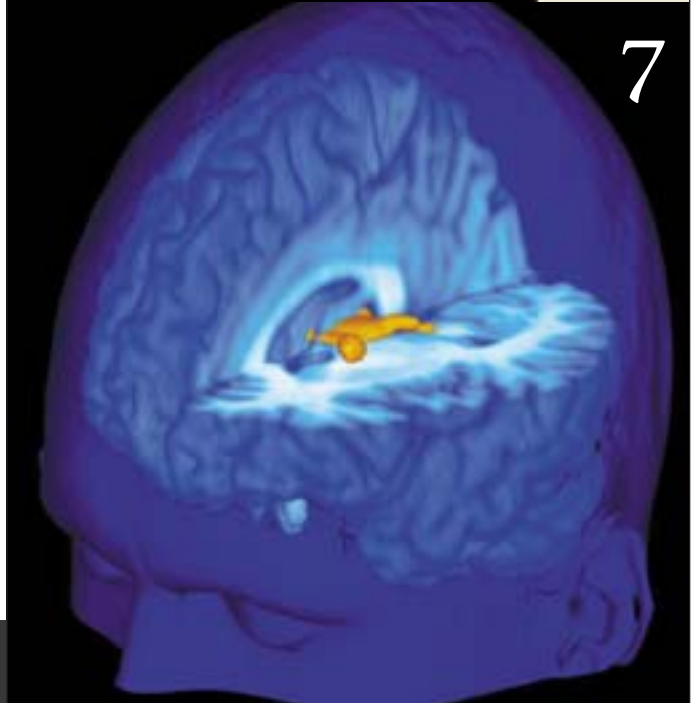
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Silent Screams

"He's a vegetable." The words evoke the image of a human being who lies permanently lifeless and unconscious. Yet how do we know that such a person's mind isn't still intact? How horrible it would be if the patient couldn't communicate yet could understand the people standing around his hospital bed, talking about him as if he were dead.

John F. Connolly, a psychology professor at Dalhousie University in Halifax, Nova Scotia, and postdoctoral fellow Yannick Marchand reported at the recent Society for Psychophysiological Research meeting in Chicago that a range of patients who are otherwise incapacitated are still processing language.

The researchers focused on a brain wave they call N400, which occurs when someone encounters a spoken or written sentence that is grammatically correct but semantically faulty. When a conscious person hears "The pizza is too hot to sing," an elec-

troencephalogram registers the presence of the N400 wave during the split second after the sentence is heard. If the person is not processing language, there is no N400.

Since 1999 Connolly's group has administered such semantic tests to 25 patients with severe brain injuries—most recently four people who were so incapacitated by a stroke, a drug overdose, a car accident and a small-plane crash, respectively, that they were deemed without cognitive function by traditional measures. Yet when the researchers read bogus sentences to the four victims, they all displayed some degree of having processed language.

Connolly says more than half of the 25 subjects have shown N400 activity,



but that may not indicate consciousness as a healthy person knows it. Although a patient studied in 1999 eventually recovered and recounted clear memories of the test, "it is very risky to make all-or-nothing conclusions," Connolly says. "Some people may be doing this reflexively, on a very semiconscious level."

Yet the possibility that

live minds might be locked inside comatose bodies induces shivers in researchers determined to learn more. Connolly's findings suggest that many supposedly vegetative patients should be tested for N400. It could mean the difference, he states, between deciding a victim is beyond help and initiating crucial rehabilitative therapy. —Chris Jozefowicz

Head Lines

In Perspective: Alzheimer's Disease

At times, advances in combating Alzheimer's disease are reported almost weekly. Among the recent news: ingesting copper through tap water might hasten the onset of Alzheimer's, whereas nicotine might help slow the memory loss that accompanies the disease. Scientists at the core of this research, interviewed by SCIENTIFIC AMERICAN, agree that the volume of study has expanded tremendously. Zaven S. Khachaturian, senior science adviser to the Alzheimer's As-

sociation, says the assault "has been growing at an exponential rate." Yet the insights gained are not necessarily leading to bona fide breakthroughs.

Alzheimer's research began attracting neuroscientists in the mid-1980s, many recruited by Khachaturian when he was a director at the National Institute on Aging. "Today you go to a neuroscience meeting, and there are thousands of presentations," says Gary Wenk, professor of psychology and neurology at the University of Arizona. The deluge could burden the research community, but, he says, "We're getting better at root-

ing out the things that waste time."

Although public funding laid the foundation for such investigation, corporate money may be the linchpin for effective therapy. Drug company executives have finally become intrigued that "a big discovery or an observation" could lead to new drugs on the market, says Paul R. Solomon, a psychology professor at Williams College. The Alzheimer's Disease Education and Referral Center now lists 25 ongoing clinical trials of treatments, in addition to five approved drugs. "Profit potential can speed things up a lot," Wenk says. —Dennis Watkins

Quieting Phantom Limbs

Dealing with a missing limb is bad enough. But of ten amputees must also struggle with confusing sensations that seem to indicate that an arm or leg is still present or that can cause disabling pain. To find out why, a team led by Herta Flor, a professor of neuropsychology at the University of Heidelberg in Germany, tested people who had had an arm amputated. The results contradict the simple assumption that phantom sensations arise from the same brain pathways that processed sensory information when the limb was intact.

Because of a physiological quirk known as passive stimulation, present in a small fraction of people, Flor was able to deliberately induce phantom sensations in five amputees by stimulating other parts of their body. Previous studies had shown that when phantom sensations amount to pain, the region of the sensory cortex that is active is the one that would normally be operating if the limb were intact. But when Flor induced nonpainful sensations—described by patients as tingling or hot—that same region was not especially active. Instead two regions thought to be involved with body image were engaged. One region, the posterior parietal cortex, helps people feel that part of their body is their own, rather than some inanimate thing. The other region processes conflicting sensory or motor information.

“The activation patterns are pretty clear,” Flor says, adding that the findings will help her group try to develop treatments for phantom sensations, possibly electrical stimulation or drugs. As many as 70 percent of amputees suffer some form of phantom pain.

—Chris Jozefowicz

Smarter in Menopause?

Peter M. Meyer was surprised when he gathered women participating in a study of menopause for a review session a few years ago. “One question came up consistently,” he says: “Am I losing my mind?”

That incident led Meyer, a biostatistician at Rush University Medical Center, and his colleagues nationwide who were charting the changes that accompany menopause to examine whether certain cognitive functions decline during this stage of life. Contrary to their own hypothesis, the researchers found that, on average, working memory and perceptual speed actually improved.

The results, published this September in *Neurology*, encompass six years of data collection from more than 800 women living in the Chicago area. The women were between the ages of 42 and 52 when the study began and were evaluated annually. Most of them improved on both the memory and perception measures over time. The general increase held for all subsets of women who were in different stages of menopause, except that postmenopausal women showed a small decrease on the perceptual speed test.

Even if higher scores could be attributed to women getting better at taking the tests, Meyer says that the data do show that menopause does not impair perfor-



mance. The outcome, he adds, indicates that women should not be anxious about mental decline during menopause—a worry that is common. Yet he notes that the evaluations did not cover all of cognition. “I think there is something there,” he says about the complaints he heard. “It just may not be showing up on these tests.”

—Chris Jozefowicz

Overcoming Fear

An experiment on mice may lead to better ways to treat people who suffer from anxiety disorders. Neuroscientists Mark G. Barad, Christopher K. Cain and Ashley M. Blouin of the University of California at Los Angeles taught mice to fear white noise piped into their cages by delivering a mild shock to the cage floor when the noise sounded. The mice would freeze in their tracks when the noise began—a classic fear response. The scientists then divided the mice into three groups. They exposed each group to the noise, without the shock, 20 times, leaving six seconds between each episode for the first group, 60 seconds



for the second group, and 600 seconds for the third group. The mice in the first group stopped freezing after 10 exposures and appeared unafraid thereafter, but the other mice continued to stiffen at the noise.

The results suggest to Barad that fears may be extinguished more effectively if confronted at short intervals. A person who avoids esca-

tors, say, would be more likely to reverse his fear by riding an escalator for 20 minutes a day for five days than for 20 minutes once a week for five weeks. Although it is known that short, repeated training intervals are best for many types of learning because they build up neural connections, “unlearning” a fear requires the brain to overcome opposition from basic neuronal survival mechanisms; fears protect us. It had not been clear until Barad’s work that any scheme of repetition could enhance fear reversal.

Barad and others are now seeking neurological mechanisms to create ways to “speed up extinction” with drugs or new treatments.

—Scotia W. MacRae

Phonics Could Prevent Dyslexia

A recent brain imaging study may provide good news for dyslexics and debate fodder for certain educators. Using functional magnetic resonance imaging, Yale University professor Sally E. Shaywitz and her colleagues have identified what appear to be two distinct types of dyslexia-related reading disorders, one of which may result from ineffective reading instruction early in life.

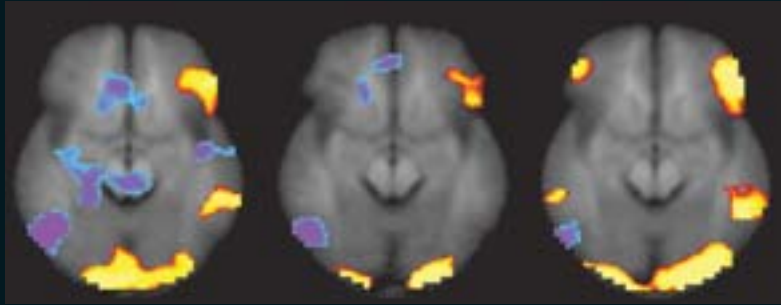
Shaywitz studied the neural activity of 27 normal readers, 19 “accuracy-improved readers” who have learned to read more accurately by going at a slow pace, and 24 “persistently poor readers” who struggle with both speed and comprehension. Images showed that the slow but accurate readers did not activate the same brain regions when reading as the normal subjects, suggesting

that they lacked some standard neural circuitry but their brains had compensated with other pathways.

More surprising, though, was the discovery that persistently poor readers showed brain activity in some of the same regions as normal readers. “It tells us that the system is there for reading but that it hasn’t been properly activated,” Shaywitz says. The poor readers also showed activity in a brain region associated with memory retrieval. She concludes that poor readers, instead of translating letters into words as normal readers do, were trying to identify words by rote memory.

If true, her view could further inform the debate over how best to teach reading to elementary school children.

Advocates of phonics—a rigorous study of the relation between letters and sounds—maintain that this approach is more effective than the “whole language” method, which is based on the belief that children naturally learn to recognize words through reading and writing. Many schools now use both approaches, although some experts say that children in general, and especially those who may have some level of dyslexia, need stronger phonics work. J. Thomas Viall, executive director of the International Dyslexia Association, hopes that studies such as Shaywitz’s will convince educators to favor phonics. “For the most part we’ve failed miserably in translating research into practice,” he says. —Daniel Cho



Slow readers (center) lack standard brain circuitry (yellow), but oddly, poor (right) and normal (left) readers use similar regions.

Half a Brain More

The basic model of brain function has been established for years: nerve cells (neurons) communicate across tiny gaps (synapses) and establish networks of connections that allow us to think, remember and jump for joy. That understanding could change dramatically if new findings about the role of glial cells—long considered to do little more than maintain a healthy environment for neurons—prove out.

The brain has even more glial cells than neurons. In the past several years, sensitive imaging tests have shown

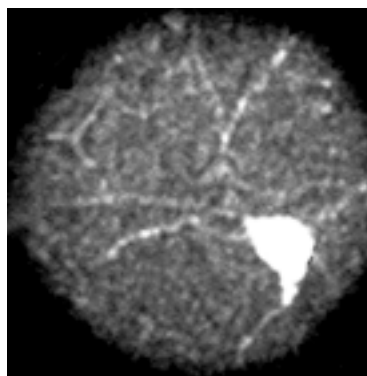
that glia communicate with neurons. And in November neuroscientist R. Douglas Fields and graduate student Beth Stevens of the National Institute of Child Health and Human Development presented evidence at a Society for Neuroscience meeting that glia also communicate among themselves, in a separate but parallel network to the brain’s neural network. The glia use chemical messaging, mediated by calcium, whereas neurons use electrical messaging via neurotransmitters.

Fields and others are beginning to

show that by communicating, glia regulate the formation of synapses and even which connections get stronger or weaker over time—the essence of learning and storing long-term memories. If this role can be confirmed, it would mean that glial cells greatly influence how well the human brain performs. Experts are cautious about assigning new prominence to glia too quickly, yet they are excited. “Cellular neuroscientists are beginning to feel as though half the brain has gone largely unexplored,” Fields says. —Mark Fischetti

Single Neuron Spied

For years, researchers have wanted to look at individual neurons in living brains. Now they can, thanks to a new, incredibly small endoscope. Mark Schnitzer developed the stiff fiber-optic instrument, which has lenses as small as 350 microns in diameter, while at Lucent Technologies’s Bell Labs. After fluorescent dye is injected into the tissue, the scope’s laser sends photons to illuminate the neurons. Detectors in the lens capture the fluorescence, and software constructs the image. The instrument,



used in lab animals so far, can resolve objects that are only several microns in size—small enough to see individual cells and their long, thin dendrites. Schnitzer, who is now an assistant professor at Stanford University, says that researchers are already using the tool to study how animals store long-term memories and that it could someday help detect brain cancers and blood clots, reducing the need for surgical test procedures. —Daniel Cho

Individual neuron (white) from a zebra finch brain.

COURTESY OF SALLY E. SHAYWITZ (top); COURTESY OF MARK SCHNITZER (bottom)

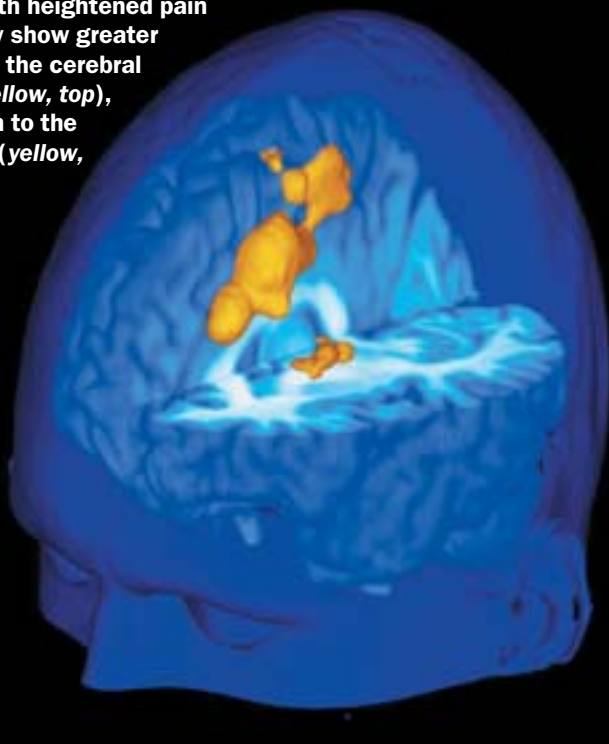
Painful Expectations

Pain may really be all in your head. Researchers at Wake Forest University and the University of Western Ontario interrogated 17 people as they applied a small pad heated to 49 degrees Celsius (120 degrees Fahrenheit) to each person's leg. First the subjects rated how hot the pad felt on a scale of 1 (a nuisance) to 10 (intense pain). Then the subjects were placed in a functional magnetic resonance imaging machine and had the same heat applied. Although the scans showed brain activity in the thalamus of all test subjects, the people who had rated the pad as hotter—more painful—also showed increased activity in the cerebral cortex, which is associated with reasoning. This correlation indicates that the subjects were getting similar information from their nerves but that the perception of the degree of pain depends on what meaning the brain

attaches to the stimuli. So says Robert C. Coghill, a professor of neurobiology and anatomy at Wake Forest and leader of the study: "Their past experience with pain, the meaning that they impart to that information, could impact heavily."

Gender and expectations may play roles as well. Researchers at the University of Florida asked subjects to hold their hand in ice-cold water until the pain became unbearable. The women, on average, kept their hand immersed for 69 seconds, whereas men lasted 109 seconds. A second group was told that the typical person of their gender could withstand the cold water for 30 seconds. This caused the tolerance time to drop to 60 seconds for the women and 91 seconds for the men. When a third group was told that the average threshold was 90 seconds, the women held out for 102 seconds and the men for 112 seconds. It became clear that men could stand the pain longer

People with heightened pain sensitivity show greater activity in the cerebral cortex (yellow, top), in addition to the thalamus (yellow, bottom).



than women, yet all subjects tried to beat the stated averages. "At least a large part of gender differences and pain has to do with expectations," says Donald Price, professor of

neuroscience and one of the investigators. He adds that previous studies of gender and pain that did not control for expectations should be reexamined.

—Dennis Watkins

COURTESY OF ROBERT C. COGHILL (top); CHRIS COLLINS Corbis (bottom)



Mitigating Trauma

The 24 months after the September 11, 2001, attacks have provided lessons about post-traumatic stress disorder (PTSD), which causes symptoms from apathy to physical illness.

The accepted wisdom is that people who have been traumatized react more excessively to new stressful events compared with people who have avoided trauma. So Yale University's Robert A. Rosenheck and Alan Fontana tracked the use of mental health services at Department of Veterans Affairs hospitals in New York City, Washington, D.C., and Oklahoma City for the six months before and six months after 9/11. After the attacks, there was no significant rise in the use of VA services by new patients or by those already diagnosed with PTSD or other mental illnesses.

More surprising, Rosenheck and Fontana found in a follow-up study that after 9/11, VA patients with preexisting PTSD were less symptomatic on admission to intensive treatment programs

and showed more improvement during treatment than did PTSD veterans who had been admitted prior to 9/11. "We attribute this to three factors," Rosenheck says: the national unity expressed after 9/11, the honors paid to veterans and the destigmatization of PTSD.

Perhaps the most unexpected results come from a study of debriefing, which seeks to prevent or mitigate PTSD by having trauma survivors share or relive their memories. After the attacks, grief and crisis counselors flocked to the area to prevent PTSD from developing in throngs of city dwellers. But a team of clinical psychologists led by Richard J. McNally of Harvard University examined these and other efforts, plus prior PTSD studies, and concluded that "there is no convincing evidence that psychological debriefing prevents PTSD."

McNally says that PTSD development is most strongly influenced by family history of mental illness, a person's network of family and friends, and the way in which the individual processes stressful stimuli. —Scotia W. MacRae

“Virtual damage” from pulsed magnetic fields is providing new insights about the brain. The procedure may help treat disorders—or even boost mental performance **BY CLAUD C. HILGETAG**

Learning from Switched-Off Brains

IT MAY SEEM BIZARRE to simulate brain damage in a healthy person with a “virtual lesion”—even when the effect is temporary and painless. But tests that use magnetic fields to deactivate selected areas of the brain show that the technique can vastly contribute to our understanding of that organ’s function.

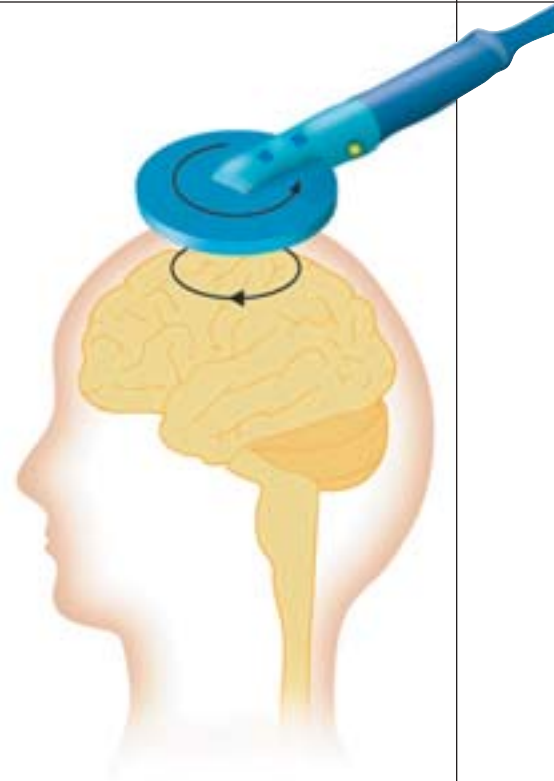
More than that, transcranial magnetic stimulation (TMS), as the approach is called, may someday be used to relieve a variety of disorders caused by malfunctioning neural circuits. For example, the U.S. Food and Drug Administration is investigating TMS as a

treatment for depression; the practice is already permitted in Canada. Other potential therapeutic targets include obsessive-compulsive disorder, schizophrenia, Parkinson’s disease, dystonia (involuntary muscle contractions), chronic pain and epilepsy. In addition to treatments for damaged brains, recent studies suggest that TMS may be used to improve normal ones, by temporarily enhancing cognition.

The Off Switch

In TMS, a mobile coil creates a strong and rapidly changing magnetic field that penetrates the skull to a depth of a couple centimeters. This field induces tiny electric currents in the brain’s circuitry, interfering with the normal biochemical processes in the local tissue. If the magnetic stimulation is repeated (rTMS) in millisecond-long pulses every second over the course of several minutes, the area becomes numb to other inputs for a short time afterward.

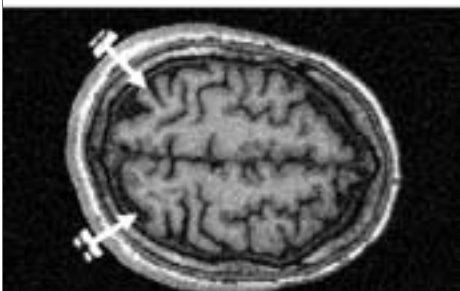
By systematically deactivating regions, scientists are reexploring and confirming knowledge about which parts of the brain are responsible for various functions—information previously gleaned over decades from studies of stroke patients. Researchers are gaining insights into fundamental neuronal mechanisms such as speech and spatial perception, which lets people quickly orient themselves in a room, find food, or cross a street safely. Substantial deficits in spatial perception lead to the severe handicaps suffered by some “neglect” patients. A stroke, brain tumor or



A coil produces a strong magnetic field that penetrates a few centimeters into the brain, interfering with the normal activities of nearby cells.

head injury can cause such victims to ignore all objects on the side of the body adjacent to the damaged side of the brain. In extreme cases, even perception of the person’s own body is affected. In his best-selling book *The Man Who Mistook His Wife for a Hat*, neurologist Oliver Sacks described such a patient, who woke up horrified to find a “counterfeit” leg in his bed.

To examine spatial perception abilities, my group at Boston University and colleagues at Harvard Medical School recently used rTMS in a study at Beth Israel Deaconess Medical Center. We asked subjects to fix their gaze on the center of a monitor and to press a key every time they saw a tiny rectangle appear on the outer edges of their vision. This attention test is comparable to the everyday situation of trying to cross a street as a car suddenly enters one’s pe-



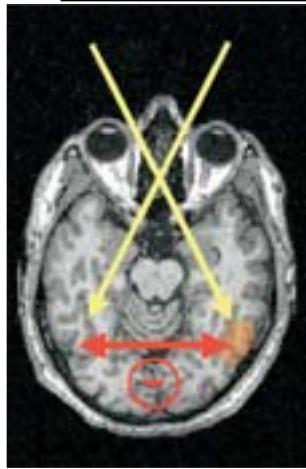
Magnetic stimulation during an experiment affected areas of the parietal cortex (arrows). The image at the top is a lateral view; the bottom one is a horizontal cross section.

(If the magnetic stimulation is repeated in millisecond-long pulses every second over the course of several minutes, the area becomes numb to other inputs for a short time.)

ripheral view. In our experiments the rectangles were so small, and they flashed so briefly, that the subjects could spot only a limited number of the total.

We applied rTMS to the parietal cortex, which is thought to be involved in attention processes. After magnetically stimulating that region for 10 minutes, we repeated the attention test. As expected, the participants showed weak neglect symptoms: they recognized fewer rectangles in the half of their range of vision that was adjacent to the stimulated brain hemisphere. But we made other, surprising observations. The “damaged” side’s perception abilities became even worse when we presented visual stimuli in the unaffected half of their range of vision. More remarkable, the test subjects recognized far more individual stimuli in the intact field than they had before the magnetic stimulation was applied. Their perception abilities in the unstimulated half of the brain had thus *improved*.

Many scientists believe that this seemingly paradoxical result might arise



While competing for spatial attention, the two responsible areas in both sides of the brain block each other (left). If the right side is deactivated by magnetic stimulation, the left hemisphere “wins”: the left visual field becomes less clear than before while the right becomes sharper.

tember 2003]. The National Institute of Neurological Disorders and Stroke, for instance, learned that TMS applied to the prefrontal cortex of volunteers enabled them to solve crossword puzzles faster. The Defense Advanced Research Projects Agency (DARPA) is looking into TMS as a means of improving

level, for one. What are its effects on neurotransmitters, gene expression and synaptic changes? Early TMS research found that it could cause seizures or epileptic convulsions, depending on the intensity, frequency, duration and level of the magnetic stimulation, and the consequences of long-term exposure

The test subjects recognized far more individual stimuli than they had before the magnetic stimulation. Their perception abilities in the unstimulated half of the brain improved.

from a competition of attention between the left and right hemispheres. One half of the brain suppresses the activity of the other, and this effect increases when the suppressing side processes stimuli more actively. In this manner, the brain probably optimizes the allocation of neuronal resources. If regions in the right half are weakened, the left is partially freed up from the normal resistance by the right side and can perform at supernormal capacities.

Boosting the Brain

Various studies add weight to the notion that rTMS might temporarily improve cognitive performance [see “Stimulating the Brain,” by Mark S. George; *SCIENTIFIC AMERICAN*, Sep-

learning and of reenergizing sleep-deprived soldiers or pilots during battle. An Australian researcher even claims to use TMS to tap inner savant skills (exceptional abilities without training) by temporarily disabling one brain hemisphere, although others have yet to match those findings.

These results are encouraging, but much work remains. We know little about what rTMS does at the cellular

are unknown. So far the FDA has not approved the method for any disorder. Despite the open questions, one thing is certain: TMS is a stimulating area for scientific inquiry.

CLAUS C. HILGETAG is assistant professor of neuroscience at the International University in Bremen, Germany, and a senior research associate in the department of health sciences at Boston University.

(Further Reading)

- ◆ **The Man Who Mistook His Wife for a Hat.** Oliver Sacks. Touchstone Books, 1998.
- ◆ **Enhanced Visual Spatial Attention Ipsilateral to rTMS-Induced “Virtual Lesions” of Human Parietal Cortex.** C. C. Hilgetag, H. Théoret and A. Pascual-Leone in *Nature Neuroscience*, Vol. 4, No. 9, pages 953–957; September 2001.
- ◆ **Virtual Neurology.** Robert Rafal in *Nature Neuroscience*, Vol. 4, No. 9, pages 862–864; September 2001.

Emotions have more influence over our solutions to ethical problems than we think **BY HUBERTUS BREUER**

Anguish and Ethics

JANE SMITH is standing at a railway switch as an oncoming train rapidly approaches from her right. Just beyond her is a fork in the track. Five innocent people, unaware of the train, are standing on the left fork. One innocent man is standing on the right. If Jane does nothing, the train will veer to the left and kill the five people. If she throws the switch, the train will veer to the right and kill the man. Should she do it? She must decide instantly: Yes, she will.

Now Jane (a pseudonym) is standing on an open footbridge that crosses a track. A runaway train is approaching at high speed. Just beyond the bridge, behind her, five people are standing on the track. The only way to save them is to push the large man immediately off the bridge into the train's path. Will she do it? Her answer comes right away: "No!"

Luckily for Jane, a student at Princeton University, she is in neither of those situations; actually, she is lying on her back in a laboratory at the school's Center for the Study of Brain, Mind and Behavior. Her head is inside a heavy white doughnut that forms the bulk of the center's functional magnetic resonance imaging (fMRI) scanner. Joshua D. Greene, a graduate student in philosophy, had told Jane to close her eyes, imagine each scenario



and answer as quickly as possible. As she rapidly tried to resolve the moral conflicts, the machine captured the increases and decreases in blood flow to

the neurons in certain regions of her brain, which Greene hopes will shed some light on how humans solve ethical problems.

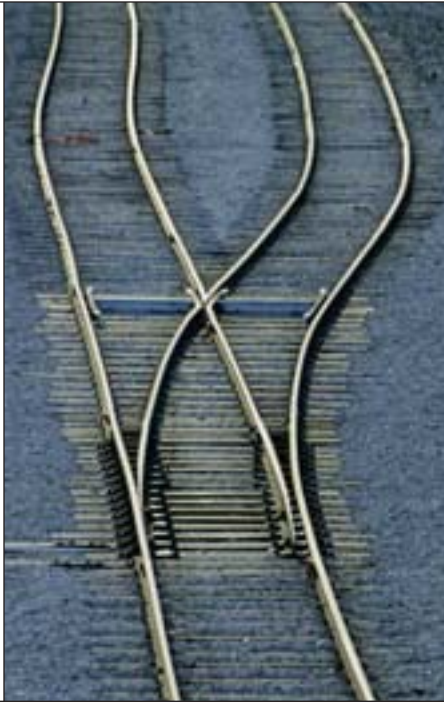
An onrushing locomotive will kill five unsuspecting people on the track unless you push a man in front of the train. Will you do it? Answer now!

PHOTODISC/GETTY IMAGES

Emotional Interference

Greene had presented the train scenarios—classics among philosophers—to Jane and other volunteers along with more than 50 other less emotionally confrontational questions, such as whether it is better to take a bus or a train from New York City to Boston to be on time for an appointment and whether one should keep the money from a found wallet.

Almost all the volunteers had decided to throw the railway switch, yet almost all decided they could not push the man into the path of the train. For years, ethicists have been unable to come up with a satisfactory explanation as to why this pattern always emerges. “Seen from a distance, it doesn’t make any sense,” Greene says.



simply provides a more realistic view of moral decision making. It is clearly useful to know how our brain acts when we ponder significant questions such as abortion or euthanasia, he says. But even though we understand that emotions are involved in decision making, we have not yet answered the question of what makes a decision ethically good or bad. It is an old truism of ethics that one’s “essence” or “being” does not inevitably determine one’s actions.

Nevertheless, fMRI is being accepted as a helpful tool. “This method allows us to get one perspective on the complex architecture of human behavior,” says Jonathan D. Cohen, director of the Princeton center. “To get a more complete view, however, we need more

(Five people stand on the left fork of a switch track. One stands on the right. A runaway train will kill the five unless you throw the switch. Will you? Answer now!)

“Both cases would have the same result”—one person dies instead of five.

Interviews with the research subjects indicated that flipping the switch, though terrible, seemed to make sense. But physically pushing a man to his death was simply too active a role to take. How does the brain reach this conclusion?

In analyzing the fMRI data since the experiments, Greene has concluded that the brain creates an emotional block at the prospect of personally shoving a man to his death. Tiny spots in the frontal and parietal lobes light up strongly as the dilemma is considered—the same regions that light up during fear or grief. Although philosophers have long held that people use practical reasoning to make moral judgments, Greene says “these pictures show that emotions play an important role.”

During the experiments, neurons in the “emotional” regions were nearly silent when the test subjects had to ponder “only” the flipping of a switch. But when the volunteers had to imagine themselves pushing the man, the emotional regions became quite active. In

addition, brain regions responsible for working memory, which are active during the ordinary manipulation of information, were considerably less active when subjects wrestled with the more difficult moral questions.

Emotions do not always prevail over logic; a few subjects said it would be okay to push the man from the bridge. Nevertheless, their inner resistance to this decision was apparent, because they took longer than the other subjects to reach their conclusion. The imaging shows that their posterior cingulate gyrus—considered to be a brain region involved in emotional processing—was working overtime, listening to a clamor of rational and emotional thoughts. These people came to the decision that the killing was justified only after great inner struggle, Greene explains.

Philosophers not Satisfied

Though fascinating, Greene’s results may not help philosophers settle important issues. For Thomas Metzinger, a philosopher at the University of Mainz in Germany, the outcome

elements—for instance, data from simulation models of our brain.”

Metzinger is looking forward to more scientific assistance: “The imaging techniques are improving, various methods will be combined, and our knowledge about how regions of the brain are interacting is constantly growing.” Perhaps scientists could construct a catalogue of brain areas and functions that is cross-referenced with behaviors that draw on similar brain processes. Someday, Metzinger says, all the approaches will help humankind take its analysis of self-awareness “to a completely new level.” And perhaps that may cause society to alter its attitudes about how people resolve tough moral judgments.

HUBERTUS BREUER is a science journalist in New York City.

(Further Reading)

- ◆ **An fMRI Investigation of Emotional Engagement in Moral Judgment.** Joshua D. Greene et al. in *Science*, Vol. 293, pages 2105–2108; September 14, 2001.

An illusion called shine-through provides a window into how the brain binds an object's component features into a coherent whole
BY MICHAEL H. HERZOG, UDO ERNST AND CHRISTIAN W. EURICH

Getting the Picture

HOW DOES THE BRAIN build a comprehensible picture of the visible world? Research over recent decades has taught us that the brain does not, in fact, process a given scene as a whole. Instead parts of the brain work independently and in parallel to process information about various aspects of each figure—location, form, color and movement. If we watch, say, a camel trot in front of a palm tree in a desert, we perceive the camel's swaying motion and dusky hue separate from its humped form. How the brain links

such features into a complete picture is not well understood and is dreaded by scientists as the "binding problem": How does a feature bind to "its" object? Why don't we experience erroneous bindings more frequently?

Our group at the University of Bremen in Germany is systematically exploring such questions in a series of experiments. By showing subjects small visual inputs for barely detectable fractions of a second, we stress the visual system so that it reveals some of its secrets.

Inheriting a Feature

In our initial experiment, observers focused their attention on a monitor. We first presented two slightly staggered vertical bars—a so-called vernier—for 30 milliseconds. Immediately afterward a grating made up of five parallel double bars appeared for 300 milliseconds. The subjects reported that they could see only the grating. Remarkably, the grating was now offset, having inherited that characteristic from the subconsciously perceived vernier. From this test, we now know that the feature of being staggered is processed independently of the vernier and then falsely bound to the outer bars of the grating, where the study participant concentrates his or her attention. Features can thus live their own lives for a short time.

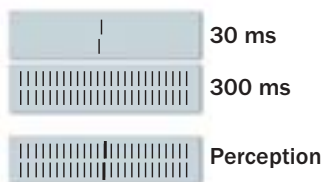
Simple changes in the grating can influence binding. When the grating has 25, instead of five, double bars, the image changes dramatically: one consciously sees the vernier superimposed on the grating. This illusion is called a shine-through element. The feature of being staggered is now correctly bound to the vernier (not to the grating), and the observer sees them as two separate items.

Which mechanisms influence which features bind to which objects? Clues may come from the ways in which the brain "segments" a scene into several discrete entities. In this manner, the brain puts the emphasis on the camel in the desert as a distinct item and interprets the animal as being different from the palm tree. To further investigate the phenomenon of segmenting, we removed two elements from the 25-bar grating. We found that the shine-through effect disappeared. The vernier was invisible, and the observers instead perceived three smaller gratings—that is, three independent objects became segmented. The middle grating again was askew.

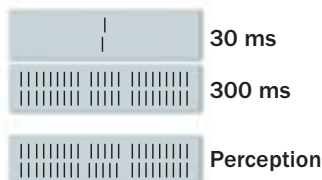
Experiments with Perception



Two staggered bars (a vernier) flash on a monitor for 30 milliseconds. A 300-ms view of five parallel double bars follows. The grating inherits the feature of being staggered in a subject's visual perception.



With a grating of 25 bars, the observer's view changes. Now the vernier "shines through" as a second element.



Shine-through disappears when two bars are missing from the grating; now the middle section shifts again.

By showing subjects small visual inputs for barely detectable fractions of a second, we stress the visual system so that it reveals some of its secrets.

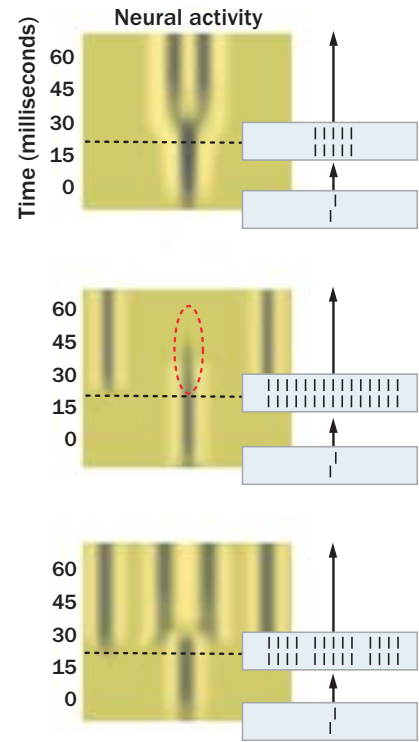
A Possible Mechanism

WE PROPOSE A MODEL that describes how visual features could be inherited, or transferred to another object, and how the shine-through illusion occurs. The neural network has two layers (*below*). Both layers receive visual inputs (*blue arrows*). Neurons submit their activity to other target neurons through links within and between the layers (*red and green arrows*). Links originating in layer A inhibit the activity of target neurons, whereas links originating in layer

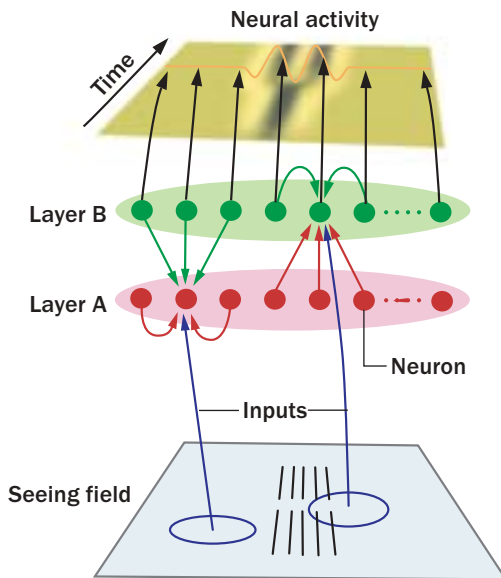
er B activate target neurons. As in a real brain, the relative strength of a link varies with the distance between neurons.

A computer simulation (*right*) shows how the activity of the second neuron layer changes over time. When a grating of five parallel double bars appears after a vernier of two slightly staggered bars, neural activity starts developing at the edges of the grating (*dark bars in top image*).

Meanwhile neural activity in the middle is suppressed by the blocking links. The observer cannot perceive the vernier, because the activity in the lower layer is too short-lived. In the case of a broader, 25-bar grating, which has edges farther away from its center, the activity of the vernier-representing neurons is blocked only weakly and the neurons stay active for a longer time (*dashed red oval in middle image*). The visual system thus segments the vernier as an independent



object from the grating, and so the observer consciously perceives it. When the test subject sees a grating with two gaps (*bottom image*), neural activity starts building not just at the outer edges but also at the gaps—again, near the vernier. In this instance, the vernier neurons are blocked, and the middle section of the grating inherits the attribute of being aslant.



An Explanatory Model

Feature inheritance and shine-through might be considered as two states of feature binding. In feature inheritance, observers see only one object—the grating—and characteristics that briefly come into view bind to it. In shine-through, study participants perceive two separate entities, but the shine-through element binds the offset feature. (The grating does not.) Any theory about the mechanisms behind this illusion has to explain why the information about the vernier offset is present during both the feature inheritance and shine-through.

Our group has proposed a model of neurological activity that can illustrate our experimental observations and can also foresee under which conditions people will segment visual inputs into objects, bind them to features and perceive them consciously [*see box above*]. Our work is thus a first step on the long road to understanding how the brain

accomplishes the task of differentiating a camel from a palm tree.

MICHAEL H. HERZOG, UDO ERNST and CHRISTIAN W. EURICH collaborate at the University of Bremen in Germany. Herzog is a biologist at the Institute for Human Neurobiology. Ernst and Eurich are physicists at the Institute of Theoretical Neurophysics.

(Further Reading)

- ◆ **Seeing Properties of an Invisible Object.** M. H. Herzog and C. Koch in *Proceedings of the National Academy of Sciences*, Vol. 98, No. 7, pages 4271–4275; March 27, 2001.
- ◆ To test your visual perception, go to http://neuro.physik.uni-bremen.de/~vernier/vernier_english/vindex.html

Islands OF GENIUS

Artistic brilliance and a dazzling memory can sometimes accompany autism and other developmental disorders

By Darold A. Treffert and Gregory L. Wallace

PHOTOGRAPHS BY ETHAN HILL

Leslie Lemke is a musical virtuoso. At the age of 14 he played, flawlessly and without hesitation, Tchaikovsky's Piano Concerto No. 1 after hearing it for the first time while listening to a television movie several hours earlier. Lemke had never had a piano lesson—and he still has not had one. He is blind and developmentally disabled, and he has cerebral palsy. Lemke plays and sings thousands of pieces at concerts in the U.S. and abroad, and he improvises and composes as well.

Richard Wawro's artwork is internationally

renowned, collected by Margaret Thatcher and Pope John Paul II, among others. A London art professor was "thunderstruck" by the oil crayon drawings that Wawro did as a child, describing them as an "incredible phenomenon rendered with the precision of a mechanic and the vision of a poet." Wawro, who lives in Scotland, is autistic.

Kim Peek is a walking encyclopedia. He has memorized more than 7,600 books. He can recite the highways that go to each American city, town or county, along with the area and zip codes, television stations and telephone networks that serve them. If you tell him your date of birth, he can tell you what day of the week it fell on and what day



Kim Peek, who is developmentally disabled, knows more than 7,600 books by heart as well as every area code, highway, zip code and television station in the U.S. He provided the inspiration for the character Raymond Babbitt in the 1988 movie *Rain Man*.

Kim Peek



Of the known savants, at least half are autistic and the remainder have some other kind of developmental disorder.

Much remains mysterious about savant syndrome. Nevertheless, advances in brain imaging are permitting a more complete view of the condition, and a long-standing theory of left hemispheric damage has found support in these imaging studies. In addition, new reports of the sudden appearance of savant syndrome in people with certain forms of dementia have raised the intriguing possibility that some aspects of such genius lie dormant in all of us.

Down's Definition

Descriptions of savant syndrome appear in the scientific literature as early as 1789. Benjamin Rush, the “father of American psychiatry,” described the lightning-quick calculating ability of Thomas Fuller, who understood little math more complex than counting. When Fuller was asked how many seconds a man had lived by the time he was 70 years, 17 days and 12 hours old, he gave the correct answer of 2,210,500,800 a minute and a half later—and he had taken into account 17 leap years.

It was not until 1887, however, that the remarkable coexistence of deficiency and superior-

Encouraging the exceptional abilities of savants can help them develop greater social skills, language acquisition and independence.

of the week it will be when you turn 65 “and can retire.” Peek can identify most classical compositions and knows the date the music was published or first performed as well as the composer’s birthplace and dates of birth and death. He is also developmentally disabled and depends on his father for many of his basic daily needs. His abilities provided the inspiration for the character Raymond Babbitt, whom Dustin Hoffman played in the 1988 movie *Rain Man*.

Lemke, Wawro and Peek all have savant syndrome, an uncommon but spectacular condition in which people with various developmental disabilities, including autism, possess astonishing islands of ability and brilliance that stand in jarring juxtaposition to their overall mental handicap. Savant syndrome is seen in about one in 10 people with autism and in approximately one in 2,000 people with brain damage or mental retardation.

ty was more completely laid out. That year J. Langdon Down, who is best known for having identified Down syndrome, described 10 people with savant syndrome. He had met these fascinating individuals during his 30 years as superintendent of the Earlswood Asylum in London. He coined the now discarded term “idiot savant,” using the then accepted classification of an idiot as someone with an IQ of less than 25, combined with a derivative of the French word *savoir*, which means “to know.”

More than a century has passed since Down’s description. Today we know much more about this perplexing set of abilities from the 100 or so cases described in the scientific literature. Savant syndrome generally occurs in people with IQs between 40 and 70—although it can occur in some with IQs up to 114 or even higher. It disproportionately affects males, with four to six male sa-



Leslie Lemke is blind and has never studied piano. Although he suffers from cerebral palsy and is developmentally disabled, he composes music and is able to play thousands of pieces flawlessly, even when he has heard them only once.

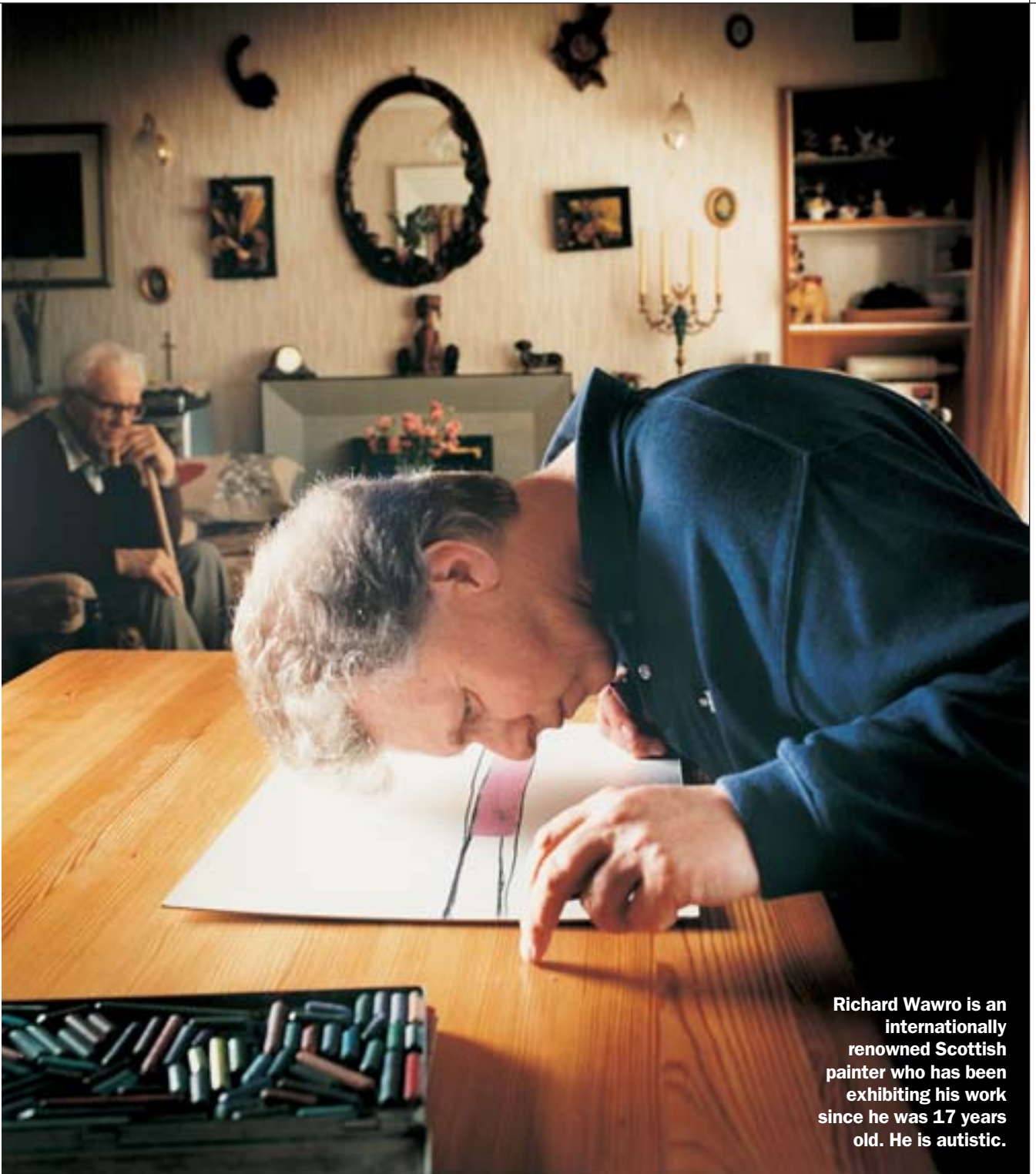
vants for every one female. And it can be congenital or acquired later in life following disease (such as encephalitis) or brain injury.

Narrow Repertoire

The skills that savant syndrome gives rise to are limited for the most part, and they tend to be based in the right hemisphere. That is, they are predominantly nonsymbolic, artistic, visual and

motor. They include music, art, mathematics, forms of calculating, and an assortment of other abilities, such as mechanical aptitude or spatial skills. In contrast, left hemisphere skills are more sequential, logical and symbolic; they include language and speech specialization [see “The Split Brain Revisited,” by Michael S. Gazzaniga; SCIENTIFIC AMERICAN, July 1998].

Most musical savants have perfect pitch and



Richard Wawro is an internationally renowned Scottish painter who has been exhibiting his work since he was 17 years old. He is autistic.

perform with amazing ease, most often on the piano. Some are able to create complex compositions. And for some reason, musical genius often seems to accompany blindness and mental retardation, as it does for Lemke. One of the most famous savants was “Blind Tom” Bethune, who lived from 1849 to 1908. In his time, he was referred to as “the eighth wonder of the world.” Al-

though he could speak fewer than 100 words, he could play beautifully more than 7,000 pieces on the piano, including many of his own works. (Some of his compositions were recorded by musician John Davis and released in 2000.)

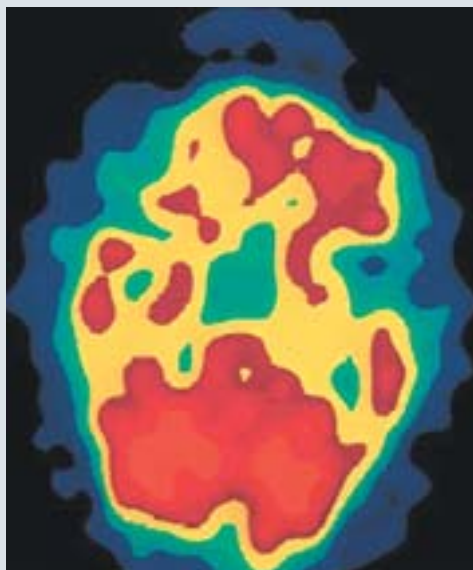
For their part, savant visual artists use a variety of media, although they most frequently express themselves through drawing and sculpture. Artis-

(Emerging Savants)

Researchers have discovered that certain patients who develop frontotemporal dementia (FTD) can paint beautifully when they previously had no such talent. In short, they have become savantlike as dementia has taken hold. This paint-

ing of horses was made by one such patient, a 64-year-old woman. Bruce L. Miller of the University of California at San Francisco has examined many FTD patients and has documented damage to the left side of their brain. One theory suggests that savant

skills may emerge in the more artistic right hemisphere as a way of compensating for damage in the left. In this SPECT image (left) of an FTD patient, enhanced blood flow can be seen in a part of the right hemisphere (red). —D.A.T. and G.L.W.



tic savant Alonzo Clemons, for example, can see a fleeting image of an animal on a television screen and in less than 20 minutes sculpt a perfect replica of that animal. His wax model will be correct in every detail, every fiber and muscle and proportion.

Mathematical savants calculate incredibly rapidly and often have a particular facility with prime numbers. Curiously, the obscure skill of calendar calculating that Peek demonstrates is not confined to mathematical savants; it seems to co-exist with many different skills.

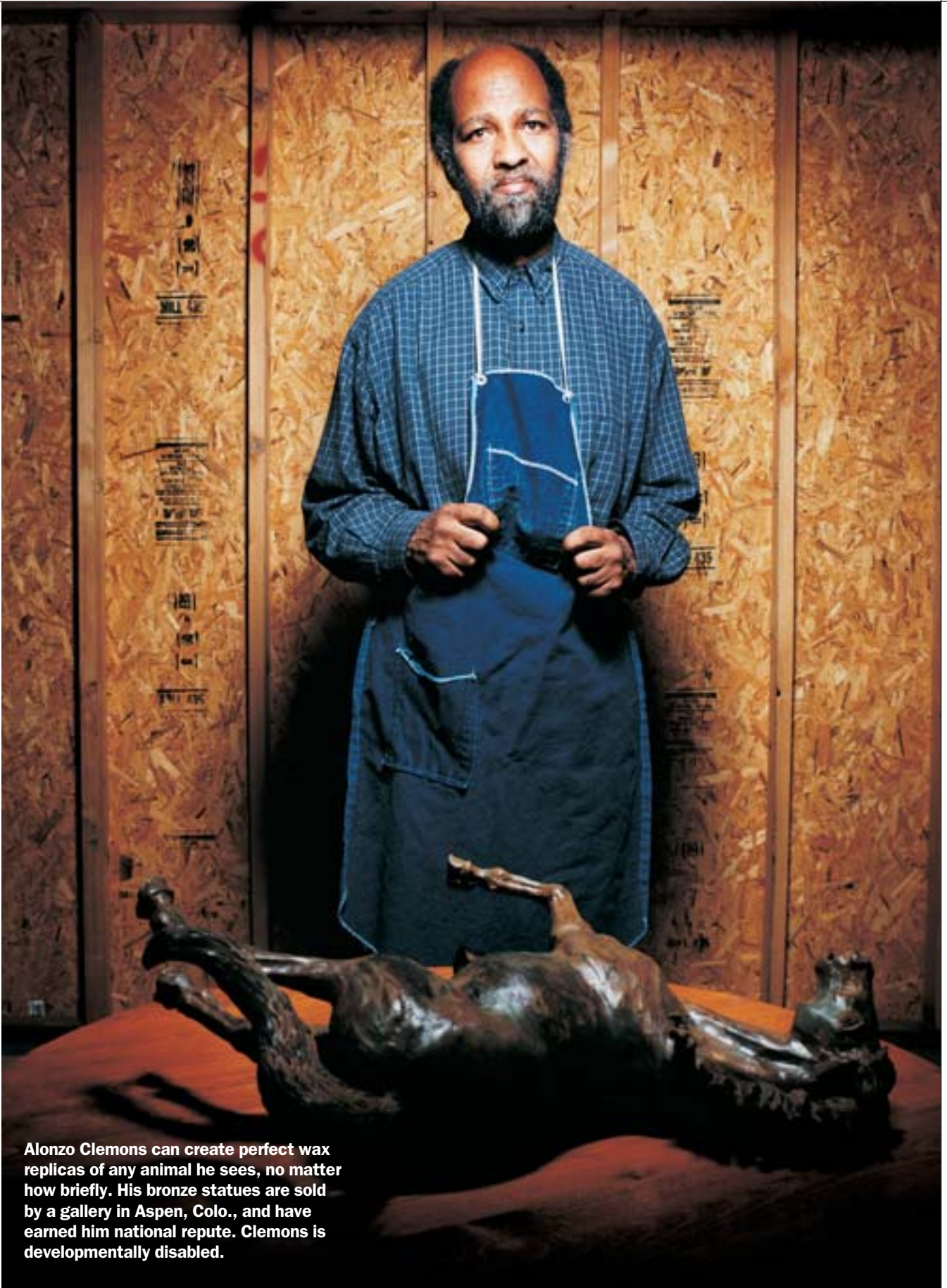
Several other abilities appear less frequently. A rare savant may have extensive language ability—that is, the capacity to memorize many languages but not to understand them. Other unusual traits include heightened olfactory, tactile and visual sensitivity; outstanding knowledge in fields such as history, neurophysiology, statistics or navigation; and spatial ability. For instance, a musical and blind savant named Ellen can navigate in thick forests or other unfamiliar spaces without running into objects. Ellen also has a perfect appreciation of passing time despite the fact that she doesn't have access to a watch or clock, even in Braille.

This ability was discovered one day when her mother let her listen to the “time lady” on the telephone. After listening for a short while to the recorded voice intone the hour and seconds, Ellen apparently set her own internal clock. Since then, she has been able to tell what time it is to the second, no matter the season.

Savant skills are always linked to a remarkable memory. This memory is deep, focused and based on habitual recitation. But it entails little understanding of what is being described. Some early observers aptly called this “memory without reckoning.” Down himself used the phrase “verbal adhesion” to characterize it. One of his patients was a boy who had read the six-volume *History of the*

(The Authors)

DAROLD A. TREFFERT and **GREGORY L. WALLACE** share a long-standing interest in savant syndrome. Treffert (dtreffert@pol.net) is a clinical professor of psychiatry at the University of Wisconsin–Madison and has done research on autism and savant syndrome since 1962, the year he met his first savant. Wallace (gregwallace@mail.nih.gov) is a research fellow in the Child Psychiatry Branch of the National Institute of Mental Health. He is conducting studies on why individuals with autism are more likely to develop savant skills.



Alonzo Clemons can create perfect wax replicas of any animal he sees, no matter how briefly. His bronze statues are sold by a gallery in Aspen, Colo., and have earned him national repute. Clemons is developmentally disabled.

Decline and Fall of the Roman Empire, by Edward Gibbon, and could recite it back word for word, although he did so without any comprehension.

Although they share many talents, including memory, savants vary enormously in their levels of ability. So-called splinter-skill savants have a preoccupation and mild expertise with, say, the memorization of sports trivia and license plate numbers. Talented savants have musical or artistic gifts that are conspicuously above what would be expected of someone with their handicaps. And prodigious savants are those very uncommon people whose abilities are so advanced that they would be distinctive even if they were to occur in a normal person. Probably fewer than 50 prodigious savants are alive at the moment.

Whatever their talents, savants usually main-

nine-year-old boy who had become mute, deaf and paralyzed on the right side when a bullet damaged his left hemisphere. After the accident, unusual savant mechanical skills emerged. He was able to repair multigear bicycles and to design contraptions, such as a punching bag that would weave and bob like a real opponent.

The findings of Bernard Rimland of the Autism Research Institute in San Diego support this idea as well. Rimland maintains the largest database in the world on people with autism; he has information on more than 34,000 individuals. He has observed that the savant skills most often present in autistic people are those associated with right hemisphere functions and the most deficient abilities are associated with left hemisphere functions.

In the late 1980s Norman Geschwind and Al-

No one knows how savants can do what they do, but research suggests injury to the left brain causes the right brain to compensate.

tain them over the course of their life. With continued use, the abilities are sustained and sometimes even improve. And in almost all cases, there is no dreaded trade-off of these wonderful abilities with the acquisition of language, socialization or daily living skills. Instead the talents often help savants to establish some kind of normal routine or way of life [see box on next page].

Looking to the Left Hemisphere

Although specialists today are better able to characterize the talents of savants, no overarching theory can describe exactly how or why savants do what they do. The most powerful explanation suggests that some injury to the left brain causes the right brain to compensate for the loss. The evidence for this idea has been building for several decades. A 1975 pneumoencephalogram study found left hemispheric damage in 15 of 17 autistic patients; four of them had savant skills. (A pneumoencephalogram was an early and painful imaging technique during which a physician would inject air into a patient's spinal fluid and then x-ray the brain to determine where the air traveled. It is no longer used.)

A dramatic study published by T. L. Brink in 1980 lent further credence to the possibility that changes to the left hemisphere were important to savant syndrome. Brink, a psychologist at Crafton Hills College in California, described a normal

bert M. Galaburda of Harvard University offered an explanation for some causes of left hemispheric damage—and for the higher number of male savants. In their book *Cerebral Lateralization*, the two neurologists point out that the left hemisphere of the brain normally completes its development later than the right and is therefore subject to prenatal influences—some of them detrimental—for a longer period. In the male fetus, circulating testosterone can act as one of these detrimental influences by slowing growth and impairing neuronal function in the more vulnerable left hemisphere. As a result, the right brain often compensates, becoming larger and more dominant in males. The greater male-to-female ratio is seen not just in savant syndrome but in other forms of central nervous system dysfunction, such as dyslexia, delayed speech, stuttering, hyperactivity and autism.

Newly Savant

In recent years, more data have emerged to support the left hemisphere hypothesis. In 1998 Bruce L. Miller of the University of California at San Francisco examined five elderly patients with frontotemporal dementia (FTD), one form of presenile dementia. These patients had developed artistic skills with the onset and progression of their dementia. They were able to make meticulous copies of artworks and to paint beautifully. Consistent with that in savants, the creativity in

(Living with Savant Syndrome)

A few reports in the literature suggest that when savants are encouraged to acquire better language skills they lose their special artistic talents. Perhaps the most famous of these cases is that of Nadia, a girl with autism who by the age of three was producing astounding drawings. When she turned seven, Nadia entered a school for autistic children that focused on verbal abilities; by the time she was a teenager, Nadia was more verbal but could no longer create brilliant and intricate drawings.

This trade-off between talent and language or socialization is not something we have witnessed. Instead the exceptional abilities of savants have proved to be strengths that are built on and used as a conduit toward normalization; these skills have helped individuals develop improved social skills, better language acquisition and greater independence. Savants gain a sense of accomplishment because of their talent; that sense, in turn, allows them to participate more fully in the world. Musical prodigy Leslie Lemke has become more animated, performing concerts and interacting with audiences. Painter Richard Wawro feels delight and excitement when he finishes a work, and he seeks out celebration. And memory wizard Kim Peek has emerged from the social isolation that characterized him before the movie *Rain Man* was made; he now travels the country talking to hundreds of school groups.

Fortunately, simultaneously encouraging savant abilities and normalization is now the generally accepted approach to such individuals' care. Savants are being placed in some classes for the gifted and talented, an opportunity that promotes social growth for both them and their



Ferry boat to Tiree, Scotland, was painted in 1978 by Richard Wawro. Wawro is cared for by his father, who enthusiastically supports his painting. Most researchers believe that encouraging such skills may help savants develop better social skills.

classmates. Some new programs, such as the one at Hope University in Anaheim, Calif., cater entirely to these exceptional individuals. Others include people with similar disorders as well; for example, music and art camps have been established for those with Williams syndrome, many of whom have savantlike musical skills [see "Williams Syndrome and the Brain," by Howard M. Lenhoff, Paul P. Wang, Frank Greenberg and Ursula Bellugi; *SCIENTIFIC AMERICAN*, December 1997]. Nurturing the talent of these people is the most fulfilling approach.

—D.A.T. and G.L.W.

these five individuals was visual, not verbal. Single-photon-emission computed tomography (SPECT) showed that injury was predominantly on the left side of the brain. Miller examined seven other patients who had developed musical or artistic ability after the appearance of FTD. He found damage on the left as well.

Miller, Craig Hou, then at Washington University, and others then compared these images with those of a nine-year-old artistic autistic savant named DB. SPECT scans of DB revealed a higher-than-normal blood flow in part of his neocortex but decreased flow in his left temporal lobe. (The neocortex is involved with high-level cognitive function; the temporal lobe is responsible for some aspects of memory and emotion.) Miller is hoping to study other artistic savants to see if the findings hold true for them as well. But the fact that DB and older FTD patients with newfound

savant skills have the same pathology is quite striking and suggests that researchers will soon be able to identify precisely the neurological features associated with savant syndrome.

The seemingly limitless memory of savants will most likely be harder to pinpoint physiologically. Mortimer Mishkin of the National Institute of Mental Health has proposed different neural circuits for memory, including a higher-level corticolimbic circuit for what is generally referred to as explicit, semantic or cognitive memory, and a lower-level corticostriatal circuit for the more primitive habit memory referred to as implicit or procedural memory. The memory of savants seems to be the noncognitive habit form.

The same factors that produce left hemispheric damage may be instrumental in producing damage to higher-level memory circuits. As a result, savants may be forced to rely on more primitive, but

spared, habit memory circuits. Perhaps brain injuries—whether they result from hormones, disease, or prenatal or subsequent injury—produce in some instances certain right-brain skills linked with habit memory function. In those situations, savant syndrome may appear.

Rain Man in Us All?

The emergence of savantlike skills in people with dementia raises profound questions about the buried potential in all of us. Accordingly, several researchers are seeking to unlock what has been called the “little Rain Man in each of us.” One

some procedures—including hypnosis; interviews of subjects under the influence of the barbiturate sodium amytal, which induces relaxation; and brain stimulation during neurosurgery—provide evidence that a huge reservoir of memories lies dormant in every individual. Dreams can also revive those memories or trigger new abilities.

No model of brain function will be complete until it can explain this rare condition. Now that we have the tools to examine brain structure and function, such studies can be correlated with detailed neuropsychological testing of savants. We hope the anecdotal case reports that have charac-

Experts believe each of us can tap into our own islands of savant intelligence that are simply overwhelmed by everyday cognition.

group has used a technique called repetitive transcranial magnetic stimulation (rTMS) in 17 normal individuals, eight male and nine female. Tracy Morrell of the University of South Australia, Robyn L. Young of Flinders University in Adelaide and Michael C. Ridding of Adelaide University applied magnetic stimulation to the area in the left temporal lobe that Miller identified as damaged in his FTD patients.

In its study, the team reports that only two of the participants experienced a series of short-lived skills, such as calendar calculating, artistic ability and enhanced habit memory. Other subjects discovered a new skill here and there, also lasting just a few hours. The researchers suggest that savant skills may be limited to a small percentage of the normal population, much as they are limited to a small percentage of the disabled population.

Nevertheless, many experts believe that real potential exists to tap into islands of savant intelligence. Allan Snyder and John Mitchell of the Australian National University in Canberra argue that savant brain processes occur in each of us but are overwhelmed by more sophisticated conceptual cognition. Autistic savants, they conclude, “have privileged access to lower levels of information not normally available through introspection.”

Our view is also that all of us have some of the same circuitry and pathways intrinsic to savant functioning but that these are less accessible—in part because we tend to be a left-brain society. Sometimes, though, we can find elements of the savant in ourselves. At certain moments, we just “get” something or discover a new ability. And

terized the literature on this topic for the past century will soon be replaced by data comparing and contrasting groups of normal and disabled people, including prodigies, geniuses and savants.

A Window into the Brain

Savant syndrome provides a unique window into the brain with regard to questions of general intelligence versus multiple forms of intelligence. It may also shed light on brain plasticity and central nervous system compensation, recruitment and repair—areas of research that are vital in understanding and treating such diverse conditions as stroke, paralysis and Alzheimer’s disease.

But savant syndrome has relevance outside the scientific realm. Many lessons can be learned from these remarkable people and their equally remarkable families, caretakers, therapists and teachers. One of the greatest lessons is that they have been shaped by far more than neural circuitry. The savants thrive because of the reinforcement provided by the unconditional love, belief and determination of those who care for them. Savant syndrome promises to take us further than we have ever been toward understanding both the brain and human potential.

(Further Reading)

- ◆ **Emergence of Artistic Talent in Frontotemporal Dementia.** B. Miller, J. Cummings and F. Mishkin et al. in *Neurology*, Vol. 51, No. 4, pages 978–982; October 1, 1998.
- ◆ **Extraordinary People: Understanding Savant Syndrome.** Darold A. Treffert. iUniverse.com, Inc., 2000.
- ◆ www.savantsyndrome.com

By Eckart O. Altenmüller

Music

IN YOUR



HEAD

Listening to music involves not only hearing but also visual, tactile and emotional experiences. Each of us processes music in different regions of the brain

TWINKLE, TWINKLE LITTLE STAR

Twinkle Twinkle
Little Star

The image shows a baby's head with musical notation and lyrics for the song 'Twinkle, Twinkle Little Star' printed on it. The notation is written on two staves. The first staff has a treble clef and a key signature of one sharp (F#). The notes are G4, A4, B4, and C5. The lyrics 'Twinkle Twinkle' are positioned below the first staff. The second staff has a bass clef and the notes G3, F3, E3, and D3. The lyrics 'Little Star' are positioned below the second staff.

It is evening, after a long day at work. I play my favorite CD: Johannes Brahms's second piano concerto. The solemn horn solo in the first two measures flows into the soft crescendo of a piano chord. A wave of memories floods my mind: pictures of the forest around Rottweil, Germany; lines from poems; that day late one summer when I was 16 years old and first discovered the concerto. The conclusion of a particular movement takes my breath away. The pianist gradually increases the tempo and volume and completely expends his energy. I feel a tingling down my spine.

We have all probably at one time or another experienced this sort of thrill from music. When music causes one of these "skin orgasms," the self-reward mechanisms of the limbic system—the brain's emotional core—are active, as is the case when experiencing sexual arousal, eating or taking cocaine. It is conceivable that such self-reward helped to lead ancient peoples to make music. Humans were already constructing the first music-making tools more than 35,000 years ago: percussive instruments, bone flutes and jaw harps. Since then, music, like language, has been part of every culture across the globe.

Some researchers believe that music also conveys a practical evolutionary advantage: it aids in the organization of community life and in the forging of connections among members of one group when disagreements occur with another. Consider forms such as lullabies, work songs for spinning or harvest time, and war marches. In recent decades, youths listen to and play certain types of music as

a means of identification and to set themselves apart from other groups.

Still, many questions remain. What happens in the brain when we listen to music? Are there special neural circuits devoted to creating or processing it? Why is an appreciation for music nearly universal? The study of music as a major brain function is relatively new, but researchers are already working on the answers.

Presstimo Nervoso: The Path to the Brain

It is helpful to review how sound reaches the brain. After sound is registered in the ear, the auditory nerve transmits the data to the brain stem. There the information passes through at least four switching stations, which filter the signals, recognize patterns and help to calculate the differences in the sound's duration between the ears to determine the location from which the noise originates. For example, in the first switching area, called the cochlear nucleus, the nerve cells in the ventral, or more forward, section react mainly to individual sounds and generally pass on incoming signals unchanged; the dorsal, or rear, section processes acoustic patterns, such as the beginning and ending points of a stimulus or changes in frequency.

After the switching stations, the thalamus—a structure in the brain that is often referred to as the gateway to the cerebral cortex—either directs information on to the cortex or suppresses it. This gating effect enables us to control our attention selectively so that we can, for instance, pick out one particular instrument from among all the sounds being produced by an orchestra. The auditory nerve pathway terminates at the primary auditory cortex, or Heschl's gyrus, on the top of the temporal lobe. The auditory cortex is split on both sides of the brain.

At this point, the picture grows more complicated, for several reasons. Observations of patients with brain injuries—a common way to gain insights about which areas of the brain are responsible for specific tasks—made over the past decades have been frustratingly varied and occasionally contradictory. Even modern imaging techniques for measuring mental activity in healthy individuals have produced only incomplete explanations of the anatomical and neurophysiological bases for the perception of music. Part of the difficulty stems from the complexity of music itself [see box on opposite page]. In addition, the various aspects of music are handled in different, sometimes overlapping regions [see box on page 28]. Last, differences among individuals have clouded interpretations of findings.

FAST FACTS

The Perception of Music

1 >> Music is a powerful form of expression that can bring us to tears—or to our feet. Like language, music has been a part of every human culture across the globe. Exactly why is a matter of debate.

2 >> Scientists are piecing together what happens in the brain when someone listens to music. The brain's response involves a number of regions outside the auditory cortex, including areas normally involved in other kinds of thinking.

3 >> The ear has the fewest sensory cells of any sensory organ—3,500 hair cells occupy the ear versus, for example, 100 million photoreceptors in the eye. Yet hearing is remarkably adaptable; even a little practice at the piano can alter mental patterns considerably.



(Dissecting “Happy Birthday”)

Imagine we’re at a birthday party. With champagne glasses in hand, we strike up what may be the most familiar number of all time: “Happy Birthday to You.” We may be thinking we’re warbling an uncomplicated tune, but a closer look at this seemingly simple eight-measure song demonstrates how complex and multilayered music actually is.

Music has four types of structures: melodic, temporal, vertical harmonic and dynamic, and each of these categories contains several subcomponents. We can start by listening to the melody as a whole—that is, we can perceive it globally or holistically. We can also break down the melody into separate length-based constituents, starting with the shortest. Taking this local, or analytical, means of perception to the extreme, we may experience the music as its individual tones. If we then put these tones together as a progression, we can consider every so-called interval between each pair.

We can also work within the context of larger temporal-perception units and concentrate on the melody’s contours. First, the melody rises somewhat, then falls and rises again in increasingly large steps up to the third “happy birthday to you.” At this timescale, the subdivision into antecedent and consequent phrases within a musical period becomes interesting. These phrases adhere to rules of symmetry and harmony and produce a rising tension and then a release. In “Happy Birthday,” the antecedent ends shortly before the last, tension-filled jump upward, leading to a softening consequent, from which the melodic line falls away.

In addition to melodies, music has temporal structures, such as rhythm and meter. A rhythm results from the temporal progression of at least three consecutive events. At the beginning of “Happy Birthday,” we

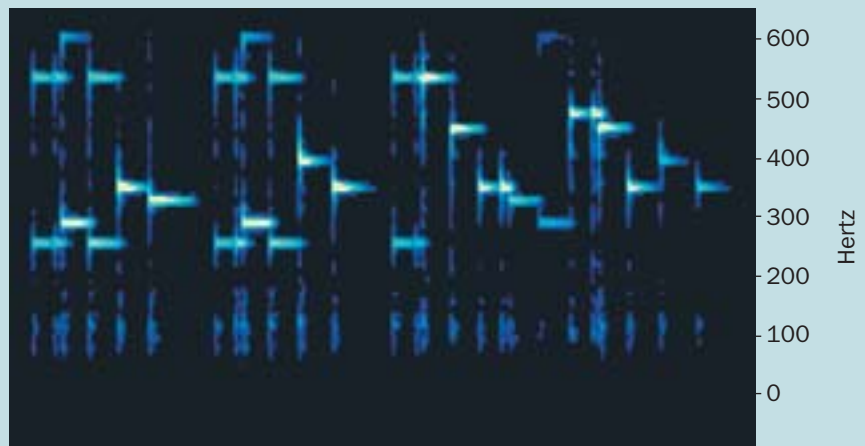
hear an energetic or punctuated rhythm. This gives the song its festive character, which is underscored by the solid, even progression of quarter notes. The meter is the regular beat, in this case three-four time, which forms the supporting basis for the melody. “Happy Birthday” is not so much a clumsy march but embodies more of the swaying, dancelike character of a minuet or even a waltz. To perceive rhythm and meter, our brains store acoustic events in a temporal context and then recognize how they are arranged.

But there is more to “Happy Birthday” than the horizontal structure made up of melodies, contours, rhythms and meter. Music also has a vertical structure: the timbre and harmony of the individual and multiple tones. The brain perceives all the different elements in milliseconds. The timbre of the birthday party guests’ voices as they sing, for example, re-

ment, we perceive the harmonies by recognizing the proportion between the number of vibrations in a given time. Simple vibrational proportions generally sound more pleasant to us than the more complex ones. These sensations are subjective: they differ from person to person and from culture to culture and can even change over time.

Finally, when listening to “Happy Birthday,” we hear its dynamic structure. The vertical dynamic constitutes volume proportions within a single tone. It arranges the individual voices by their stressing or backing off from the foreground or background of the tone area. The horizontal dynamic describes the volume progression within a group of consecutive tones. This dynamic has a strong effect on the listener’s emotions.

One key characteristic of how we hear music is that we can switch among types of perception, only a few



Complex patterns make up music. In the “Happy Birthday to You” melody, a spectrograph’s horizontal lines represent the individual tones’ frequency spectra (left to right). The dynamic structure is represented by color: louder tones are lighter. Octave intervals appear on the left side (red lines); at the bottom is the standard pitch A440.

sults from sounds and transient phenomena created by phonation (the production of speech sounds) and by the combination of the singers’ harmonics. If we hear the song sung by several voices or with accompani-

of which are described here. We can also quickly become engrossed in the music, thereby again changing the way we are listening. Somehow “Happy Birthday” doesn’t sound quite the same anymore. —E.O.A.

Where Does the Brain “Hear”?

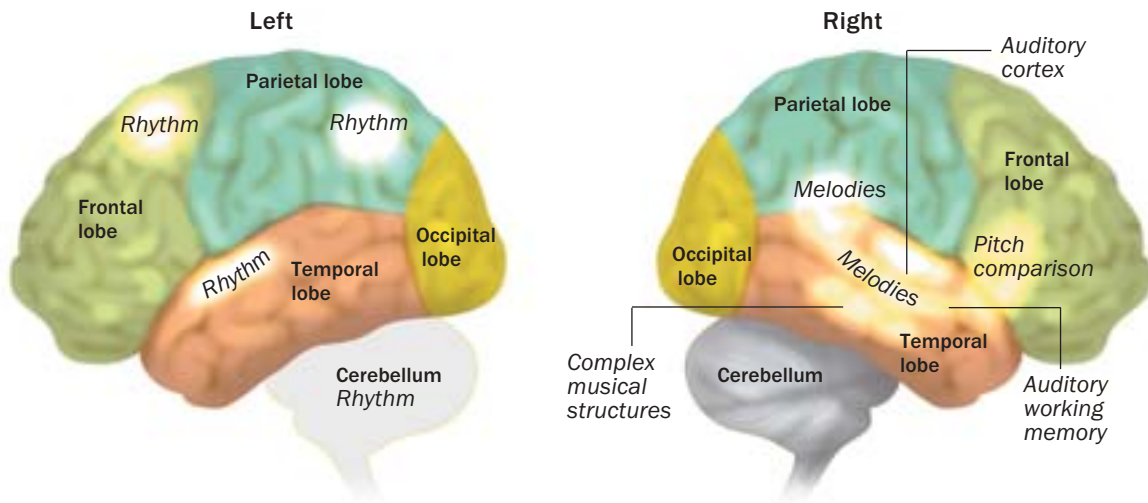
Left Hemisphere: Rhythm

Music is processed in various areas of the brain, which change depending on the focus of the listener and his or her experience. When the brain of an amateur musician processes simple rhythmic relations in a melody, such as the variance in length between certain tones, he utilizes the premotor, or movement-preparation, regions as well as sections of the parietal lobe in the left hemisphere. If the temporal relations among the tones are more complex, premotor and frontal lobe regions in the *right* hemisphere become active. In both cases, the cerebellum (which is commonly supposed to be involved in movement control) also participates. In contrast, musicians who are discerning between rhythms or meter predominantly employ parts of the frontal and temporal lobes in the right hemisphere. Rhythmic relations display a similar picture: people who are not musically trained process in the left side, whereas experienced musicians generally do so in the right.

Right Hemisphere: Pitch and Melody

When a musical layperson compares different pitches, the right posterior frontal lobe and right upper temporal lobe convolution are active. The tones are stored for future use and comparison in the auditory working memory located in the temporal region. The middle and lower areas of the temporal lobe are also active when processing more complex musical structures or structures being stored in memory for a longer period. In contrast, professional musicians show increased activity in the *left* hemisphere when they are differentiating among pitches or perceiving chords.

When the listener is focusing on whole melodies rather than individual tones or chords, entirely different sections of the brain become active: in addition to the primary and secondary auditory cortices, the auditory associative regions in the upper temporal lobe are at work. In this case, the activity is once again concentrated in the right hemisphere.



Despite the gaps, scientists are piecing together a general understanding of where the brain “hears” music. We know, for example, that both sides, or hemispheres, of the brain are involved, though asymmetrically. For a long time, it was common to believe in a distinct division between the left brain’s processing of language (the side that also handles reasoning tasks) and the right brain’s processing of music (the half that contains emotional and spatial information). Many medical textbooks included this simplified theory until the 1980s. In recent years, however, researchers have established that injuries to either side can impair musical abilities. This happens not only in the case of damage to the auditory areas in the temporal lobe but also when associated regions of the frontal lobe and the pari-

etal regions are affected. (If the Heschl’s gyrus is destroyed on both sides, incidentally, total deafness does not occur. Instead the ability to distinguish between various sounds is severely impaired. A patient with this condition would not be able to understand language or perceive music at all.)

Early stages of music perception, such as pitch (a note’s frequency) and volume, occur in the primary and secondary auditory cortices in both hemispheres. The secondary auditory areas, which lie in a half-circle formation around the primary auditory cortex, process more complex music patterns of harmony, melody and rhythm (the duration of a series of notes). Adjoining tertiary auditory areas are thought to integrate these patterns into an overall perception of music. Farther for-

ward, behind and to the sides lie the so-called auditory association regions. (Wernicke's region, in the left hemisphere, which plays a major role in the perception of language, is located here.)

My studies of stroke patients with Maria Schuppert, also at the Institute for Music Physiology and Performing Arts Medicine, and with other colleagues also support the theory that the perception of music is organized hierarchically. The left brain appears to process such basic elements as intervals (the spaces between individual tones) and rhythms (the duration of a series of notes). The right brain, in comparison, recognizes holistic traits such as meter (beat) and melodic contour (the pattern of rising and falling in a piece). If the left side is damaged, patients generally become incapable of perceiving rhythms. If, however, the right side is injured, the patient no longer recognizes contours, melodies, meter or rhythm.

Andante Adaptable: The Role of Learning

Past experiences and training have a significant effect on where and how the brain processes music. Laypeople and professional musicians show several significant differences.

or to, say, pianists when it comes to locating the sources of sounds.

But only a few hours of training can demonstrate how plastic the perception of music can be. Pantev, now at the Rotman Research Institute at the University of Toronto, and his colleagues played music, which had a certain range of frequency filtered out, for test subjects. After just three hours, the subjects' primary and secondary auditory cortices were notably less active in response to this frequency band.

Experienced listeners also register musical structures such as intervals and rhythms more accurately. Scientists at our institute conducted numerous studies of the changes that occur in the brain when a subject undergoes musical instruction or "listening cultivation" exercises. Gundhild Liebert conducted these tests in our EEG (electroencephalogram) laboratory with the help of Wilfried Gruhn, professor emeritus at the Freiburg Music School in Germany. Thirty-two music students had to identify 140 major, minor, diminished and augmented chords played at random. Each chord was sounded for two seconds, followed by two seconds of silence for "internal listening." Af-

Past experiences and training have a significant effect on where and how the brain processes music.

For instance, scientists have investigated the perfect, or absolute, pitch that some people possess. Individuals with this ability can name a musical note when it is played alone, without the need for another note for comparison. Musicians with perfect pitch have a larger anterior, upper temporal lobe convolution in the left hemisphere. It seems that for perfect pitch and for the enlargement of that brain region to occur, musical training must begin early, before the age of seven.

Intensive musical training for years also leads to heightened activity in the corresponding brain regions, as reported in 2001 by Christo Pantev, then at the University of Münster in Germany. The "musical" brain structures of professional trumpet players react in such an intensified manner only to the sound of a trumpet but not, for example, to that of a violin, and vice versa.

Directional hearing abilities also sharpen with exercise. Conductors, who must be continuously aware of the musical balance of the entire orchestra, can pay close attention to members who sit near the edges of the group. They are also superi-

ter a half-hour session, a subset of the subjects received a standardized listening-cultivation lesson on cassette tape, which was meant to help them recognize the differences between diminished and augmented chords. The rest read short stories during this time. All the subjects then listened to the same chords they had heard previously, but in a different order.

When subjects heard the chords for the first time, the frontal and temporal regions were active in both brain hemispheres. Immediately thereafter, however, activity generally decreased in the participants who had not undergone the listening-cultivation session. The trained group, though, recognized the chords more readily and also displayed more activity in the central brain regions that connect sensory perception with motion perception,

(The Author)

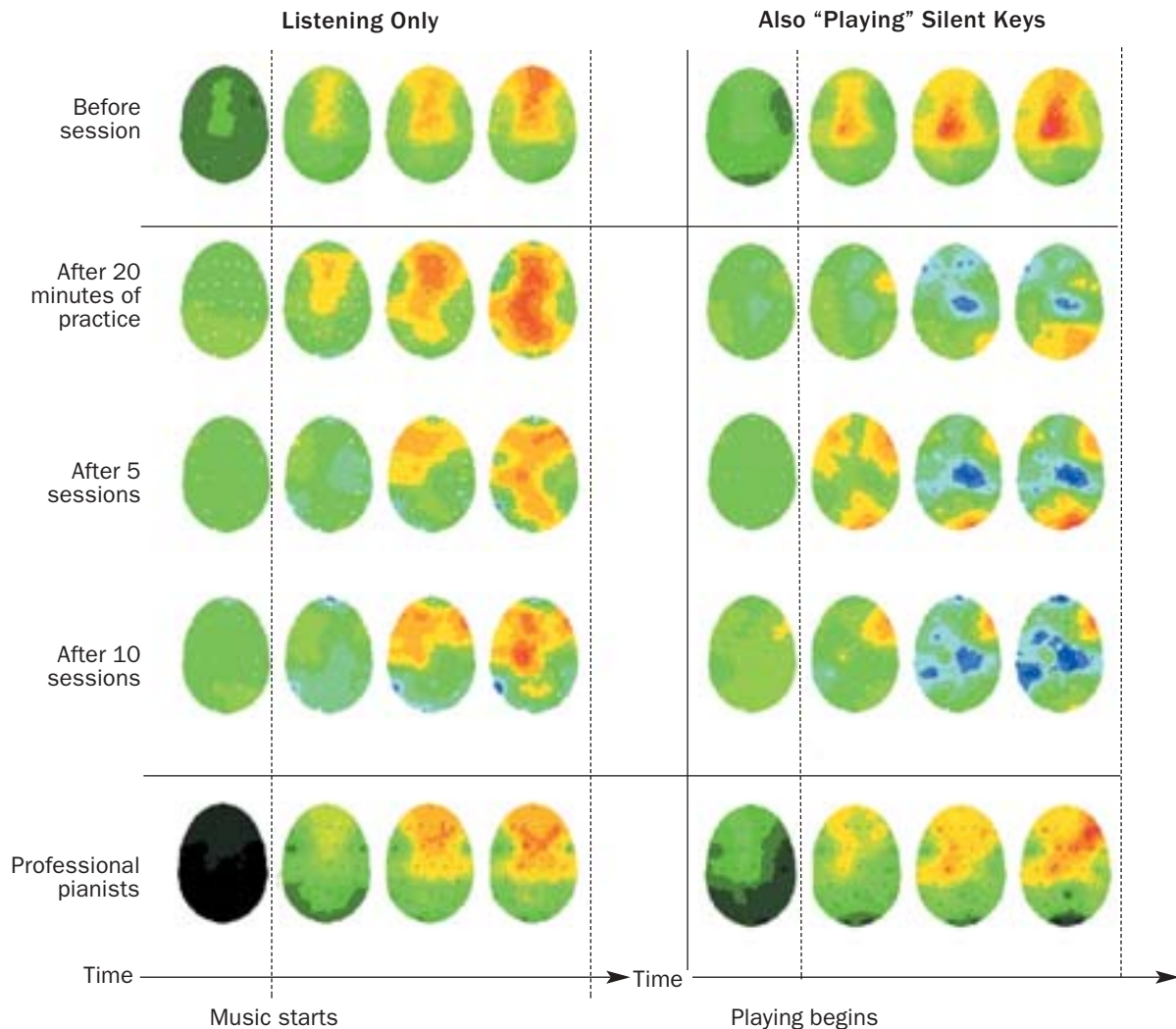
ECKART O. ALTENMÜLLER directs the Institute for Music Physiology and Performing Arts Medicine at the Professional School of Music and Theater in Hannover, Germany. Music is also part of his life outside the lab: he plays the flute.

Helping Hands for Hearing

A connection between areas of the brain involved in listening and motor activities becomes clear in electroencephalogram (EEG) images of the top of the head (nose pointing upward). Amateur musicians first either simply listened to a simple piano melody or listened as they “played” silent electric piano keys (*top*). Next, in a series of practice sessions, the subjects listened and then played the pieces themselves, but this time they could hear what they were

playing. After just 20 minutes, activities in the auditory and tactile regions began to change: when participants were simply listening to tunes, their sensory motor regions became active (*middle rows*). By the end of the experiment, the subjects’ patterns of mental activity began to resemble that of professional pianists (*bottom*). —E.O.A.

- Increased activity
- No change in activity
- Reduced activity



especially during the internal listening phase. How could these be connected?

Menuetto Corepresentativo: The Ear and Hand Cooperate

The researchers learned the answer when they asked the subjects whether they had employed any specific listening strategy. Several students stated that after the training, they had pictured the chords

as they would be fingered on a piano keyboard. Almost all the participants had practiced their listening skills at home on a piano. It is possible that the lessons could have brought the mental representation of the keyboard fingering—the information about how to play certain chords as stored in the cortex—to the forefront.

To find out how much time the brain needs to create such connections, my colleague Marc Ban-

gert, also at the institute, measured the brain activity of amateur musicians in two different situations: they either simply listened to short piano melodies or they listened while also “playing” on electric piano keys, which produced no sound. He found two completely different activity patterns. Then he ran a practice phase. Participants listened to simple piano melodies and then played the pieces themselves. This time the subjects were able to hear what they were playing. Whenever a subject mastered a particular melody, he would be given a more difficult one, until he was no longer able to show improvement. Generally, the subjects became proficient at 20 to 30 melodies during the 11 training sessions.

The result: after the first 20 minutes of piano practice, activity patterns in both the auditory and the tactile regions of the brain began to change slightly. Three weeks later the changes were clearly present. (We measured one subject again a year later and found that the changes remained intact,



Test subject wears a “bathing cap” with 32 electrodes in an experiment using an electroencephalogram, or EEG, to determine which areas of the brain become active in response to music.

bol (notes on a score) and so on. Not so in the brain of an unpracticed listener.

Last, music can elicit strong emotions, which researchers have recently begun to investigate with imaging techniques. The limbic system, which lies below the cerebral cortex and is responsible for emotions, is intensely involved: music perceived as pleasant stimulates parts of the frontal lobe and also a region called the gyrus cinguli, located far-

(Thus, our studies underscore an important fact: humans perceive music as more than just sound.)

although she had not practiced the piano at all since the training.) When listening to tunes, the participants’ sensory motor regions became active, even when they did not move their hands in the slightest. If the subjects then began to finger the silent keys, other regions in the frontal and temporal lobes became involved. By the time the experiment ended, participants showed neural activity patterns similar to those of professional pianists.

Thus, our studies underscore a very important fact: humans perceive music as more than just sound. During a concert, we watch the musicians play, using visual perception; louder passages create vibrations, which we perceive as tactile stimulus. If a person is playing a piece on an instrument, the music is perceived as a series of fingerings and therefore is also a sensory motor activity. If one studies notes on a page, the music is registered by symbolic means, requiring the processing of abstract information. In each of these modes, we can represent music in our brains and store it in our memory systems. When we play musical instruments, our brains must be continuously processing auditory information together with sensory motor data. Bearing this out, in imaging studies the same music is represented in multiple ways in the brain of a professional musician: as a sound, as movement (for example, on a piano keyboard), as a sym-

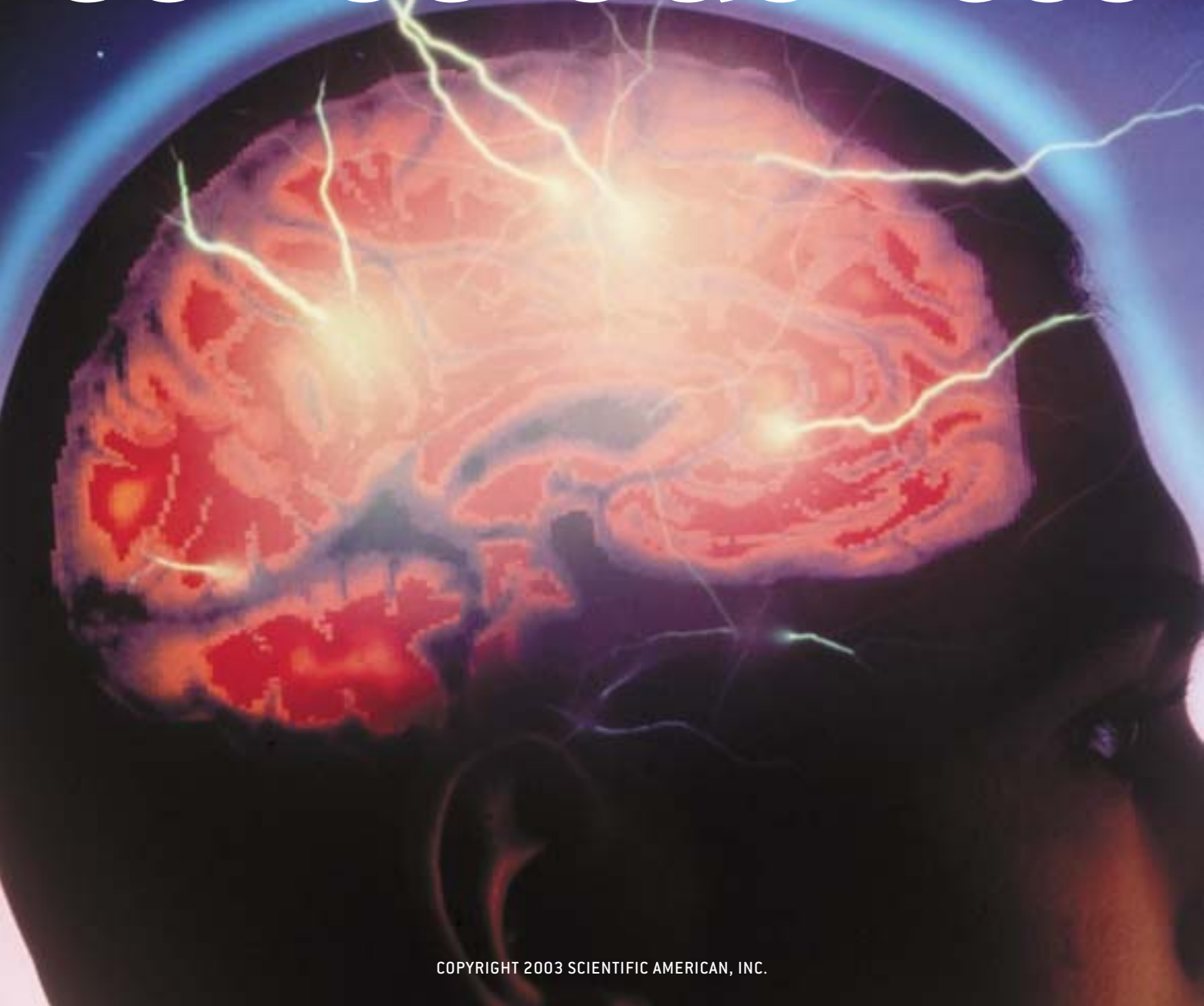
ther toward the center of the brain. Music perceived as dissonant and unpleasant, however, elicits activity in the right gyrus parahippocampalis, close to the underside of the brain. Feelings about the music itself can also influence the brain’s processing. Our work group found that when teenage test subjects liked a song, parts of the frontal and temporal lobes on the left side were predominantly active. If they found the music less enjoyable, the corresponding sections of the right brain were more active.

What, then, can we conclude about how our brains process music? If music is experienced variously by each person, in different regions of the brain, it is difficult to find rules that apply universally. Therefore, in the strictest sense, the world today holds about six billion unique “music centers”—one for every human brain. The brain structures that process tunes in each of those music centers adapt quickly to new circumstances. We are only now beginning to recognize and investigate this neuronal dynamic.

(Further Reading)

- ◆ **How Many Music Centers Are in the Brain?** Eckart O. Altenmüller. *Annals of the New York Academy of Sciences*, Vol. 930; 2001.
- ◆ **The Cognitive Neuroscience of Music.** Edited by Isabelle Peretz and Robert Zatorre. Oxford University Press, 2003.

the quest
to find
consciousness



By studying the brain's physical processes, scientists are seeking clues about how the subjective inner life of the mind arises

by Gerhard Roth

What is the nature of consciousness? Asking the question is simple, but determining the answer is not. Consciousness can seem utterly familiar, even mundane. People excuse themselves for “unconsciously” ignoring someone at a party or profess that they seek to “expand their consciousness.” But a true understanding of the phenomenon remains elusive.

How do the brain's physical systems work together to create the subjective experiences of the mind—the self-reflective, private thoughts that make us who we are? Noting the difficulty of using empirical science to quantify something so subjective, David J. Chalmers, a philosopher at the University of Arizona, has dubbed this the “hard problem” [see “The Puzzle of Conscious Experience,” by David J. Chalmers; *SCIENTIFIC AMERICAN*, December 1995].

An artist's conception depicts the mysterious brain activity involved in consciousness.

For a long time, the topic was left to philosophers, but that has changed in recent years as neuroscientists have taken up the challenge. Francis Crick of the Salk Institute for Biological Studies in San Diego and Christof Koch of the California Institute of Technology, for example, have argued that a sound approach to exploring the mechanisms of consciousness is to concentrate on finding what are called the neural correlates—the processes in the brain that are most directly responsible for consciousness. Locating the neurons in the cerebral cortex that correlate best with consciousness, and figuring out how they link to neurons elsewhere in the brain, may provide key insights.

Recent advances in imaging techniques have made it possible to observe which areas of the brain are at work during various types of mental activities. Consciousness may be one of the greatest unsolved puzzles of neuroscience, but by learning more about the processes involved, researchers are at least gradually identifying the pieces.

Many Levels

Any effort to understand consciousness must begin by noting that it comprises various states. One should therefore not refer to *the* consciousness, as is often the case in philosophical discussions. At one end of the spectrum is the so-called alertness (or vigilance) state. States of lower consciousness include drowsiness, dozing, deep sleep and on down to coma.

The characteristic stream of consciousness consists of two forms: background and actual. Background consciousness encompasses long-lasting sensory experiences, such as a sense of personal identity, awareness of one's physical body, control of that body and intellect, and one's location in

space and time. Other elements include the level of reality of one's experiences and the difference between that reality and fantasy. Background consciousness provides the foundation for the second type: actual consciousness. The concrete, sometimes rapidly alternating states of actual consciousness include awareness of processes in one's own body and the surrounding environment; intellectual activities, such as thinking, imagining and remembering; emotions, feelings and needs (such as hunger); and wishes, intentions and acts of will.

Attention is an important feature of consciousness. Events that do not command our attention hardly exist for us, even if they influence how we perceive, feel or react. Attention, in the sense of concentration, sharpens the actual states of consciousness. The more we concentrate on one single event, the more other events will fade out of our consciousness.

In everyday life, our brains perceive and process a great deal of information that never reaches our consciousness. Neuroscientists refer to these subconscious data as implicit perception and implicit learning. Most experts feel that such unconscious perception leads to a "flat" processing of information: one recognizes objects, occurrences or connections by means of obvious physical characteristics and simple rules. No details or complex content is recognized, however. In contrast, we can consciously give an account of complex tasks involved in explicit perception and explicit learning.

Traits of attention and actual consciousness are present when the brain confronts events or problems that it judges to be important and new. With the aid of various types of memory, the brain classifies perceptions according to whether they are important (or unimportant) and known (or unknown). If something is categorized as unimportant, it will either not make it to consciousness at all or it will do so only in an imprecise way. Information that is "important but known" brings about the activation of processes that have already dealt with it previously, and therefore the brain can take routine actions that require a minimal level of consciousness. Only when an occurrence or task is important and new—for example, when a person must solve a complex problem or learn a new motor skill—do the systems for consciousness and attention fully activate. Consciousness is, in this case, a specific method for processing information that would be too intricate for subconscious processes.

Many tasks, particularly those that require practice, must first be consciously perceived. Driving a car, riding a bicycle, playing the piano—to learn such skills, we must concentrate on them.

FAST FACTS

The Rise of Awareness

- 1» How does consciousness, with its private and subjective qualities, emerge from the physical information processing conducted by the brain? The problem is so challenging that for a long time it was left to philosophers.
- 2» Recently neuroscientists have focused on the neural correlates—the activities in the brain that are most closely associated with consciousness.
- 3» To date, no "center" for the phenomenon has revealed itself, but advances in imaging have helped in the study of the brain areas that are involved during consciousness.

With increased practice, we can reduce the level of concentration and alertness. If we then turn our attention to the smaller details, we can actually disrupt the action's smooth progression.

Signposts of Consciousness

In the past few years, neuroscientists have discovered regions of the brain that contribute to con-

sciousness and have formed theories about what those regions may be doing to contribute to that unique form of awareness. A historically important tool of such research is the study of patients with injuries to specific areas of the brain. Observations of results, however, do not reveal much about the neural mechanisms that underlie consciousness. Finding such information requires methods that

Gateway to Consciousness

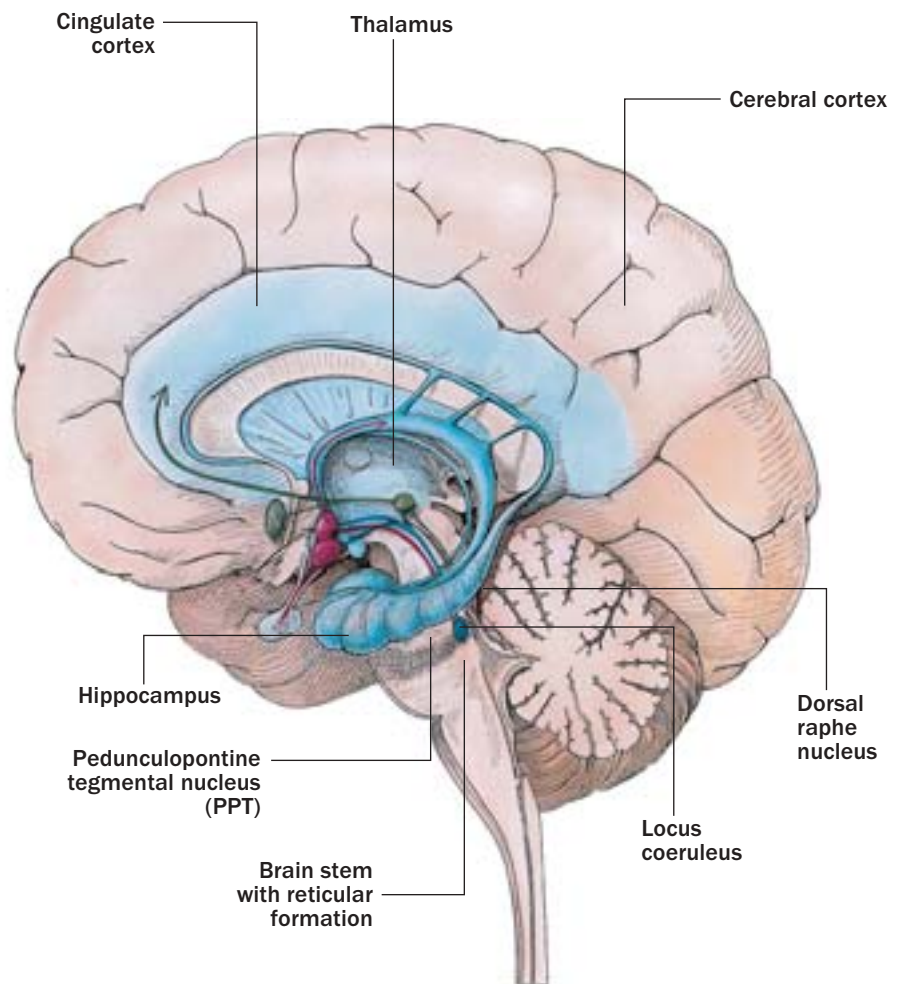
Individuals consciously perceive only that information processed in the associative regions of the cerebral cortex. But many regions that operate on a subconscious level participate in the various states of consciousness.

One example, in the brain stem, is the reticular formation, (meaning "little net," which the structure resembles) formation, which helps to regulate the general state of activity and consciousness in the cerebral cortex. The reticular formation receives signals from various neural pathways and acts as a kind of filter; it alerts the higher cognitive functions when a stimulus is novel or persistent. Its fibers project widely through the brain, many through the thalamus (considered to be the doorway to the cerebral cortex).

The reticular formation has cell groups called nuclei. The medial nucleus group comprises the ascending reticular activating system. It receives messages from all the sensory systems regarding processes in the body or its local environment. As soon as the systems detect a significant change, it and areas of the thalamus work to increase the cortex's general level of activity, thereby increasing one's state of alertness.

The median and lateral nucleus groups, particularly the dorsal raphe nucleus, the pedunclopontine tegmental nucleus (PPT) and the locus coeruleus ("blue spot"), operate more specifically than the medial group. The neural tracts of the locus coeruleus are believed to report the presence of new or conspicuous stimuli to the brain and the cortex via the neuromodulating

chemical noradrenaline. The PPT and basal forebrain signal the importance of the stimuli via acetylcholine, thereby influencing the degree of focused attention and memory formation. The raphe nuclei, involved in emotions and cognition, seem to dampen their targeted areas, mainly the cortex, by means of serotonin.



A cross section of tissue from a mouse's cerebral cortex shows that individual nerve cells are arranged in layers (the tissue was colored for greater visibility).



register neural activity, beginning on the level of individual cells or even their synapses (points of connection), up to the cortical networks that contain millions or billions of nerve cells. Special imaging procedures help to provide clues: magnetic encephalogram (MEG), positron emission tomography (PET) and functional magnetic resonance imaging (fMRI). The electroencephalogram (EEG) records electrical brain waves.

Using these techniques, researchers have learned that individuals consciously perceive only information that is processed in the associative regions of the cerebral cortex. Elementary processing activities outside the cortex cannot be accessed by consciousness. The many states of consciousness thus represent the end product of extremely complex, yet completely unconsciously processed, activities. Even the feeling that we are free in our intentions and actions—the subjective impression of free will—is molded by centers that work unconsciously. Consciousness may have an “advisory” rather than a decisive role in shaping our actions [see “Does Free Will Arise Freely?” on page 40].

What happens, then, in the associative regions when we experience a given state of consciousness? The various states are thought to be based on split-second “rewiring” in the cortex’s neural networks. These networks consist of millions of nerve cells that are densely interconnected. The synapses can strengthen or weaken their connections for a short

time, which alters the manner in which information is processed locally. In this way, nerve cells from specific sections of the networks temporarily share the same state of excitement. For instance, when the brain is attempting to recognize one object among many objects or to comprehend the meaning of a sentence, a group of nerve cells temporarily forms a single meaning unit. The combination of connections between the thalamus (an important switching center) and the cortex (which operates more on a localized and spread-out level) seems to play a major role in the emergence of synchronized activities.

Thinking in One-Second Intervals

In the brain regions that are relevant to consciousness, chemicals are released that modulate, or influence, the rapid changes in the synapse strength of the cortical neurons. The so-called reticular formations and the limbic centers exercise significant control in this release [see box on preceding page]. The messenger material (the “quick” neurotransmitters such as glutamate or gamma-aminobutyric acid), which is responsible for the transfer of signals between nerve cells, operates in a matter of milliseconds. Neuromodulating processes, and the chemical reactions caused by them inside a cell or on a synapse, require much more time—approximately one second or even longer. This could be the basis for the characteristic one-second interval of consciousness: the period during which perception, imagination, thought and memory are released.

Neuromodulating processes require relatively large amounts of oxygen and glucose. The corresponding replenishment through an increase in the

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THORSTEN LAUX

local blood flow occurs within seconds. Here is one example of how the process works. Imagine having to quickly identify an object within a complex scene. At first, one must concentrate, resulting in a corresponding effort in the temporal and occipital

lobes. The strength of synaptic connections is altered in existing networks, or new networks are formed until a solution is found. After several repetitions of the task, these cortex connections are more vigorous, enabling completion with less men-

Emotions and Memory

Emotions are shaped “subcortically,” as neurobiologists say, by the impact of the limbic system’s centers on the cerebral cortex and by memories of one’s experiences.

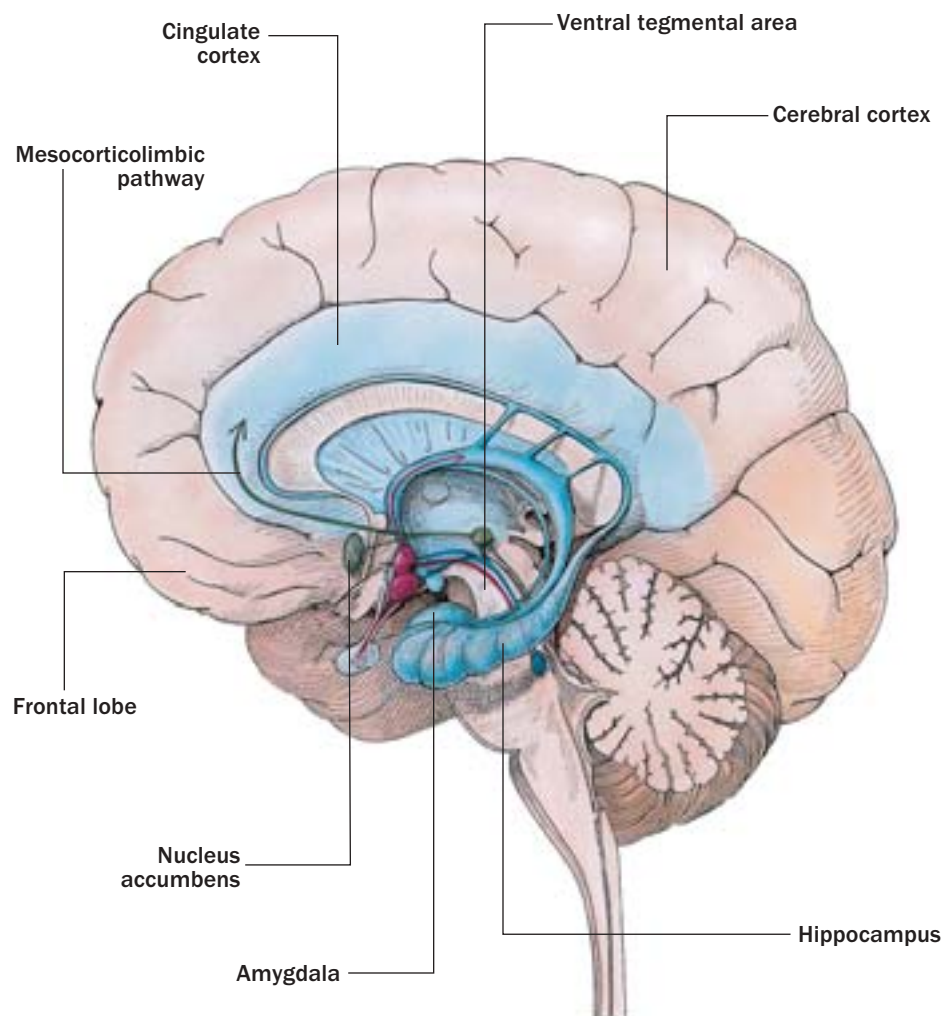
The amygdala, an almond-shaped nucleus of the limbic system, plays a central role in emotion. The structure generates and processes unconscious emotional states and experiences, mainly recognizing stimuli from the environment that are considered terrifying or that could be physically damaging. Some researchers believe that the amygdala also takes part in nonfear-related emotions, such as curiosity and the will to action.

The emotions of desire, satisfaction and contentment are most closely related to activities in the mesolimbic system, which consists of the nucleus accumbens and the ventral tegmental area. By using the neuromodulator chemical dopamine and the so-called brain’s own opiates, the mesolimbic system alerts the other brain centers, particularly the cerebral cortex, when a positive or desirable circumstance presents itself.

Memory content, which is mediated by the hippocampus and the surrounding cortex, is also critical in consciousness. Brain researchers also call conscious memory “declarative memory.” Scientists differentiate between two types of declarative memory. Semantic memory comprises facts not relating directly to people, locations or time. Episodic memory, in contrast, includes concrete experiences relating to the self. The core of

episodic memory is the autobiographic memory, which forms the foundation of the self and self-awareness. According to current theory, the hippocampus is responsible for episodic memory, and the surrounding cortex controls semantic memory.

The cingulate cortex sits between the limbic system and the cerebral cortex. It is involved in controlling alertness and in the emotional coloring of perception (for example, when experiencing pain). In addition, the cingulate cortex works closely with the frontal lobe to control the recognition and correction of mistakes.



tal effort; a PET or fMRI of the brain would show an almost immeasurably small amount of cortical activity. Similarly, after sufficient practice to acquire a learned motor skill, a person can complete the movement “in his sleep” and can even mull other thoughts simultaneously. Networks involved in the action gradually become reduced in size and are shifted to the motor cortex and to deeper motor centers such as the cerebellum and the basal ganglia (which operate unconsciously).

The brain is constantly trying to automate processes, thereby dispelling them from consciousness; in this way, its work will be completed faster, more effectively and at a lower metabolic level. Consciousness, on the other hand, is slow, subject to error and “expensive.”

Associations in the Brain

Why are only those processes that take place in the associative cortex accompanied by consciousness? A cursory look reveals nothing obvious. That area of the brain does not vary that much in appearance from the rest of the cortex. It, too, consists of six different layers with a relatively homogeneous cellular makeup. Its points of entry and exit are coordinated on the individual layers, just as is the case in the rest of the cortex. But the answer may lie in those connections themselves—and the astonishing number of them.

The primary and secondary sensory regions of the cortex are concerned with an initial, low-level processing of information from the sensory organs. The associative regions become activated afterward [see box on opposite page]. For example, in-

formation travels from the eyes through the thalamus first to the primary and secondary visual cortex, and from there it goes to the various visual associative regions in the parietal and temporal lobes. But there are also many reverse connections back to the primary and secondary regions. Neurons in the associative areas respond to input in a much more complicated manner than do cells in the sensory regions—they work in a highly integrative way. Specific nerve cells in the transitional zone from the parietal, occipital and temporal lobes react to visual and auditory stimuli; visual and tactile stimuli; or visual, auditory and tactile stimuli.

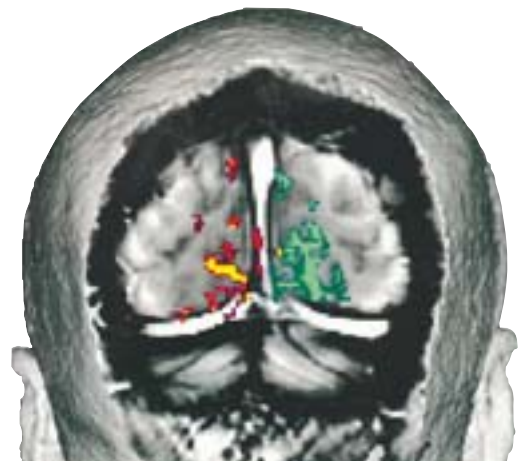
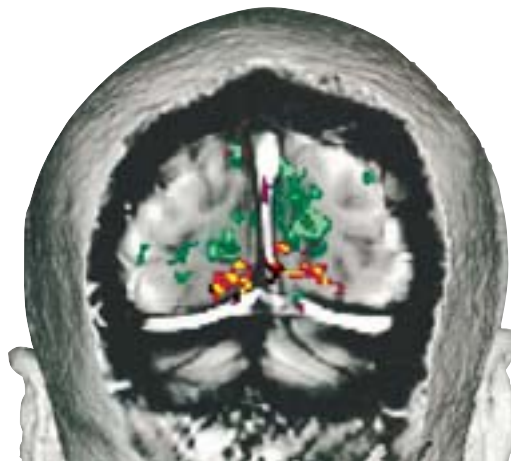
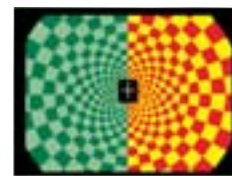
The associative cortex has a much stronger overall connection than the other cortices to the hippocampus (the organizer of cognitive memory) and the limbic system (particularly to the amygdala, the organizer and possible center of emotional memory). These cortical regions appear to be extremely important in producing the different states of consciousness [see box on preceding page].

The development of consciousness seems to be largely reliant on the numerous nerve cells in the cortex being linked to other cells. The cortex’s high number of connections vastly exceeds the number of points of entry and exit. This arrangement means that the cortex communicates with itself more than with the sensory organs and motor apparatus.

Synchronized Firing

Neuroscientists can thus outline which functions the states of consciousness fulfill and which physical, chemical, anatomical and physiological conditions are necessary in the brain for the development

Blood-flow variations in the visual cortex demonstrate how a subject’s brain responds to a pattern being viewed. The colors in this image show the cortical activity corresponding to the subject’s view of either the vertical or horizontal half of the pattern. The experiment may illuminate a neural correlate of visual consciousness.



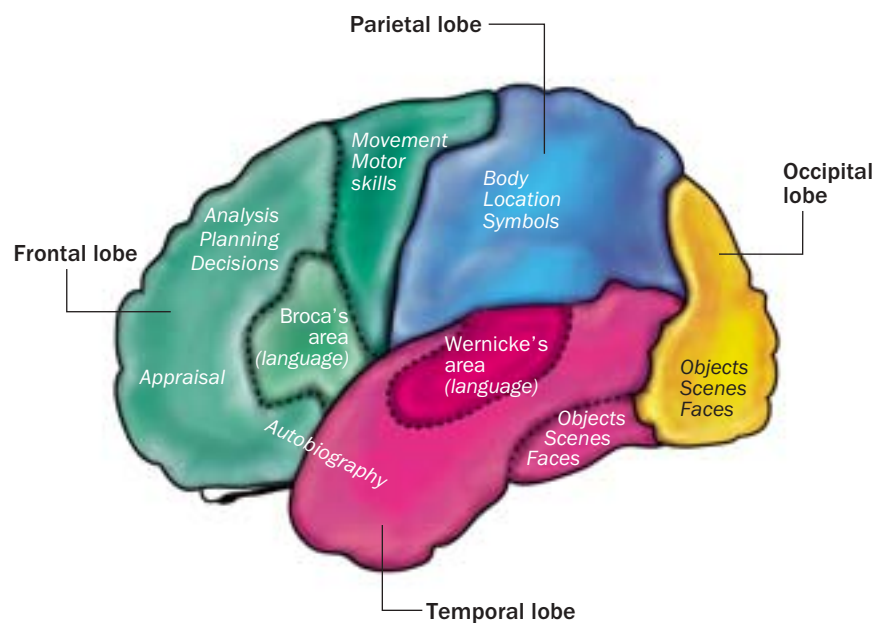
The Seat of Consciousness

Consciousness is involved only in activities stemming from the associative regions of the cortex. (The other cortex regions are for sensory and motor functions.) These regions are found in the neocortex, or isocortex, which consists of four lobes: the occipital, parietal, temporal and frontal. The associative cortex is involved with the conscious perception and identity of one's own body; in the planning of movement, spatial perception, orientation and imagination; and in spatial alertness.

The temporal lobe's associative cortex is responsible for sight and hearing. Its lower section and the bordering areas of the occipital lobe recognize objects, faces and scenes. The middle and upper regions process sounds, melodies and language. The language center known as Wernicke's area is found here (in the brain's left hemisphere in most people); it registers the meaning of words and simple sentences.

The frontal lobe's associative cortex is divided into an upper and a side region, called the prefrontal cortices, as well as a region above the eye sockets called the orbitofrontal cortex. The prefrontal cortex helps to structure sensory perception corresponding to a given time and location. It also enables individuals to act and speak according to a specific plan and context, solve problems, and rework the content of thoughts and actions. Its activity thus creates the foundation of conscious plans and intentions for action. The orbitofrontal cortex is mainly occupied with the internal formulation of goals, motivation and emotions, as well as with the evaluation of the consequences of one's own actions. Some researchers refer to this as the seat of morals and ethics and therefore of our conscience. The language center known as Broca's area is also found in the frontal lobe.

The imaging processes PET and fMRI take advantage of the fact that brain regions with neurons in a more excited state display a higher metabolism. When a test subject observes objects, faces or scenes, activity increases in the transitional area between the lower occipital and temporal lobes. If the test requires the analysis of complex sentences, Broca's area is tapped. The cingulate gyrus, a cerebral convolution of the limbic system, displays excitement when a person experiences pain. If one has to reach more complex decisions when performing an action, the prefrontal cortex and the orbitofrontal cortex are active. These so-called neural correlates give scientists clues about the mechanisms of consciousness.



of these states. Yet we are still left with a critical question: How does consciousness occur? Many theories have been put forward, but no consensus yet exists; a number of the ideas give a central role to interactions between the thalamus and the cortex.

One good candidate explanation might be found in the synchronization of the billions of cortical nerve cells with the trillions of synapses—which are all the while under the influence of the reticular formation, thalamus, hippocampus and limbic systems. The astronomically high occurrence of internal rewiring in the associative cortex adds weight to this idea. Learning more about the properties of the links in the brain's neural net-

works could yield insights about emergent characteristics such as personal experience.

For now, no definitive explanations exist, but that is not likely to remain true forever. Consciousness has a rather unique character, but at least some of the mysteries that surround it should nonetheless—eventually—fall away in the face of persistent scientific inquiry.

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By Michael Pauen

Does Free Will Arise *Freely?*

How consciousness is produced influences when we can regard fetuses as individuals, whether courts can hold us accountable for our actions, and other hot issues

If we reach convictions and decisions by directly processing information in neurons, then we may be puppets dependent on the wiring of our brains.

It's Monday morning, and Mr. P steps out of his house, headed for the trolley that will take him to work. The air is still brisk, but as he strides down the sidewalk, rays of sunshine fall on his face. "How nice and warm!" he thinks, and he decides to walk the entire way to the office, even though it will take 10 minutes longer than the trolley. He makes a right turn and heads downtown.

Before he reaches the next corner, Mr. P has already forgotten the episode. To philosophers, however, such ordinary occurrences involve problems so extraordinary that they have wrestled with them for more than two centuries. Somehow the nerves in Mr. P's skin and the neurons in his brain registered the sun shining on his face as a feeling he experienced as "pleasant," and that sensation prompted him to take a sudden, delib-

erate action. Everyone knows what this chain of events feels like. But no one knows the exact connection between simple neuron activity, our subjective response to it and the exercise of our free will. Are the neural activity and the sensation of "pleasant" ultimately one and the same, or does the conscious feeling arise as a secondary effect of the nerve activity?

This question is one example of the famous mind-body problem: What is the relation between our body's physical processes and our consciousness? Are the brain and mind the same or different entities? For some time, we have known that conscious processes are based mainly in the cerebral cortex. But recent, more detailed information indicates that consciousness has components that are processed in separate areas of the brain. As research continues, we may soon know the neuropsychological basis for consciousness. Neuroscientists and cognitive scientists may then be able to replace the endless philosophical debates with empirical scientific descriptions.

Or the neuroscientists may end up raising a whole new series of fundamental philosophical questions. Assume for a moment that researchers discover that we reach convictions, judgments and decisions through the direct processing of information by neurons. Would this mean that Mr. P did not make his decision to walk to work of his own free will but rather reacted as a puppet, dependent on the wiring of neurons in his thought-processing organ?

Regardless of the answer, the question shows that brain activities are entwined inextricably with human self-conception. Therefore, we need to draw on philosophy to assess biological advances made in solving the brain-mind puzzle. How do the processes in the brain relate to consciousness? Is it even possible to explain consciousness scientifically? And if so, how do the results influence our self-image of having free will and accountability for our actions?

No More Than Neurons

For centuries, many philosophers held that the mind was an autonomous entity, often conceptualized as a "homunculus," or miniature version of a human who observed what was taking place in the brain. Today consciousness is generally

FAST FACTS

The Nature of Consciousness

1 >> Recent laboratory work indicates that consciousness is processed in many different brain regions. If researchers can define the neuropsychological basis for consciousness, then scientists may be able to replace the endless philosophical debates with empirical descriptions about whether the brain and mind are the same or different entities.

2 >> The difference between the brain and consciousness may be the way in which information is accessed. If access is via an internal perspective—such as experiencing the sun's warmth on one's skin as pleasant—the processes are within consciousness. If access is via external perspective—observing other people looking up at the sun and smiling—the processes are neuronal.

3 >> But if mental activities equate with brain processes that follow predictable rules, then we cannot claim to have freedom of will. Our behavior would be determined by the rules governing our neurons.

4 >> Freedom requires a self—a person—that can determine itself; this determination distinguishes a free action from one that occurs by rote. The self is a kind of core containing the most fundamental personality traits and convictions that define a human being.

viewed as the representation of a group of mental processes—such as convictions, desires or the sense of dread—that we experience directly from our first-person perspective. “Direct” means that we become aware of these states without having to depend on input from our senses and without having to form any conclusions.

As Mr. P walks, for example, he is assembling assumptions about what the other people on the street are thinking or feeling, based on facial expressions or other information he experiences indirectly, through the filter of his senses. But he has direct access to his own thoughts and desires, and only he himself has this access.

This brings us to the first question noted above: How do the processes in the brain relate to consciousness? We can tackle this from one of two prevailing philosophical viewpoints. So-called dualists believe that the brain and mind draw on separate types of processes. Monists assume that one type of process underlies both the brain and mind.

For dualists, Mr. P’s perceptions lead to nerve impulses that cause him to take a different route. Neuronal activity influences the perception of mental processes, too; as Mr. P turns the corner and continues walking, he finds that the street is quite shady, and he regrets his decision not to take the trolley.

Dualists, however, also maintain that mental and physical processes are in contrast to one another—which is problematic for the scientific community. This precept makes it very difficult to explain how nonmaterial processes (the mind) influence material activities (the brain). Today’s monists do not have this difficulty, because they consider mental processes to be second-order ef-



Perhaps “conscious mental fields” arise from neuronal activity in the same way that magnetic fields arise from electric currents in a wire.

PHOTODISC GREEN/GETTY IMAGES

fects that arise from the material world. “Conscious mental fields” arise from neuronal activity in the same way that magnetic fields arise from electric currents in a coil of wire. This position is much more in line with a scientific view, but before we can accept it as truth we must at least empirically prove the existence of the interaction—that a conscious mental field can be found and defined. Today we have no clues to explore this phenomenon.

According to monists, our heads possess only one type of process, regardless of whether it is active in mental or neuronal activity. The difference between the brain and consciousness is the way in which information is accessed. If access takes the form of an internal perspective in the first person—such as experiencing the sun’s warmth on one’s skin as pleasant—then the processes are within one’s consciousness. If access takes the form of an external perspective in the third person—observ-



THOUGHT EXPERIMENT 1: A neurobiologist, Mary, knows everything about human color perception but has never been able to see a color herself. Does Mary's perfect knowledge enable her to know what it is like to perceive color? Or would she experience something completely new if she were to see colors for the first time?

ing other people on the street smiling and looking up at the sun—the processes are neuronal.

Even though this theory may seem a bit artificial, everyday existence proves that seemingly divergent phenomena are often simply two sides of the same coin. When one goes to a concert and sees and hears a cello playing, one uses two distinct types of access that belong to the single process of perception. But as long as they are in agreement spatially and temporally, one would never differentiate between an “acoustic” and an “optical” cello.

Colors and Bats

If the difference between brain and consciousness is attributed to our utilizing two forms of access, then no one can claim that “reality” deals only with neuronal processes. Body and mind are of equal importance. Neither is more true than the other, and neither is more worthy of scientific study. For monists, mind processes are identical to brain processes.

Yet one problem remains. Even if we could identify the neuronal processes that form the basis for a particular type of conscious activity, we would not yet *understand* how the activity of the

nerve cells relates to our conscious experiences. This is the key to answering our second question—whether a scientific explanation for consciousness is even possible.

A philosopher would attempt to formulate this problem a bit more clearly. What is important is the difference between a mere *determination* that consciousness becomes involved under certain neuronal circumstances and our ability to *explain* why this occurs. Even though we can determine precisely what takes place in our brains' neurons during a given process in the consciousness, that determination clarifies only that these processes occur under a certain set of circumstances. It does not explain why exactly these and not some different circumstances are present.

We can get a better idea as to what this means by analyzing two famous thought experiments. One concerns Mary, a highly resourceful neurobiologist who knows everything there is to know about human color perception. Unfortunately, Mary has never been able to see a color herself. Does her perfect knowledge of color perception enable her to know what it is like to perceive color? No; if she became able to see color for the first time, she would experience something complete-

PHOTODISC RED/GETTY IMAGES

ly new. This view, however, means that neurobiology knowledge cannot supply us with any firm conclusions regarding processes in our consciousness—which would lead us to believe that it is extremely unlikely that we will ever find an explanation for the relation between the brain and consciousness.

The picture becomes even less clear with our second thought experiment, which was formulated by philosopher Thomas Nagel of New York University in the 1970s. Assume again that consciousness is nothing more than a process in the brain. Also assume that we know absolutely everything about the physical processes in the brains of bats. Would we then have a clear sense of the bat’s consciousness? Would we be able to know “what it’s like” to be a bat?

In both examples, we lack the necessary explanation. We can accept the determination that certain neuronal processes are linked to specific mental processes. But we do not understand why those processes are present and others are not, and we do not know what would occur subjectively if the neuronal processes were to change. Thus, we do not know if bats—or lizards or earthworms—possess a consciousness. This realization makes it difficult to answer more disturbing questions: At what point can we claim that a fetus possesses a consciousness and, therefore, should be regarded as an individual, capable of experiencing pain?

Explanations Still Elusive

Some philosophers and scientists argue that knowledge of neuronal processes is, in principle,



THOUGHT EXPERIMENT 2: A neurobiologist, Tom, understands every neuronal process that occurs in the brains of bats. Would he be able to have a bat’s consciousness—would he know “what it’s like” to be a bat?

As neuronal processes develop, consciousness changes. At what point can we claim that a fetus possesses consciousness and can experience pain?

ARTUR CUPAK/MAURITIUS

not well suited to formulating explanations regarding consciousness. But this viewpoint may well underestimate the progress that further scientific discovery could bring about. For example, it was implausible for people of the 1600s and 1700s that white light was composed of colored light, a concept formulated by Isaac Newton. Leading scientists, including Robert Hooke, disagreed fundamentally with Newton’s theory. Yet today it is common knowledge that white light consists of a full spectrum of colored light. With acceptance of this discovery, we have gained ac-

cess to plausible scientific explanations for many more optical phenomena.

To understand consciousness, what we need are more objective characteristics that are recognizable from the outside. We already know many traits of the various states of consciousness [see “The Quest to Find Consciousness,” on page 32], but our knowledge is inadequate. It is too early to

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If consciousness is identical to a certain activity in the cortex, then we cannot claim to have freedom of will. We would be acting as marionettes that are dependent on the wiring of our particular neurons.



say that a comprehensive explanation of consciousness will ever develop, yet we have just as little proof that we should rule out the possibility.

Is Freedom Only an Illusion?

As we learn more about consciousness, we must also consider the implications. Assume for a moment that we could prove that consciousness

really is synonymous with a certain activity in the cortex's neurons. We would then have to deal with our third big question: What are the consequences for human self-conception?

If our mental activities equated with processes in the brain that followed predictable rules of nature, then we could not claim to have freedom of will. We would not determine our own behav-

Our legal system is founded on the idea that we can be held accountable for our actions. If not, we would have to make sweeping changes.

ior—it would be determined by the rules governing our neurons.

As much as we may not like this argument, it is hard to disagree with its logic—until we realize that freedom is connected to two conditions. We would never refer to behavior as being free if it were somehow required by an external source. And freedom must also be set apart from coincidental occurrence. If it were merely a coincidence that the nerve cells in Mr. P's brain fired, causing him to decide to walk to work, then the decision did not stem from free will but was a random occurrence. Actions of free will must be attributed to a person, thereby assigning a kind of creatorship to this freedom. We can adhere to both criteria if we translate "freedom" as "self-determination." This translation is much more than just a word game. It clarifies something that is usually overlooked in discussions of free will: freedom requires a person, a "self," that must determine itself. The determination of the self distinguishes a free action from one that occurs merely by rote.

What is this "self"? It is not an internal soul or homunculus that steers our fate. Instead it is a kind of core containing the most fundamental personality traits and convictions that define a human being. For example, if I believe that theft is a reprehensible act, then I will bring all the goods I pick up in the grocery store to the cashier and pay for them. This action is a product of my free will, directed by my determination of myself.

So what does it mean for our freedom of will that convictions and therefore the incitement of our actions are based on activity in the brain's nerve cells?

If a specific conviction is the basis for an act of free will, that free will is not threatened by the fact that this conviction has a neuronal basis. The opposite is actually the case: by realizing a central personality trait, the neuronal process can provide our wishes and convictions with the power to act—it forms a condition for self-determined action. Our self-determination is not in danger when our moral concepts and convictions are realized on a neuronal basis.

This situation does mean, though, that philosophers would be unable to explain such self-determined decisions. That would have to be done by the neuroscientists. Yet neuroscientists would

have to ascertain whether individual actions really are determined by central personality traits or whether they are reliant on external factors.

Act before You Think

According to our definition of self-determination, central personality traits must be consciously active at all times. Even when actions are triggered by preconscious processes, our behavior must still be considered as self-determined. Therefore, the oft-discussed experiments done in the 1970s by neuropsychologist Benjamin Libet of the University of California at San Francisco do not fundamentally contradict the view that there is such a thing as self-determined behavior. Libet found that certain simple actions, such as walking or moving one's hand, are already initiated by neuronal processes before a person makes the conscious decision to produce the action. It is debatable what conclusions are allowed by his experiment, but it is clear that the experiment does not refute the idea of self-determination; the brain's processing of physical sensations that make it aware the body is walking may simply be slower than the time it takes to process the instructions to walk. It is possible that these experiments could change our view of the role our consciousness plays in our decision making.

Knowledge of our consciousness and its physical basis can help us understand how we form our views of reality. Consciousness and self-determination also lie at the foundation of most basic legal and ethical questions. Our entire legal system is founded on the idea that we can be held accountable for our own actions. Should this assumption be proved false, we would be forced to make sweeping changes.

Consciousness and the ability to determine our own actions are central to our notion of being human. Our views play a major role in some of the most hotly debated subjects of our time. The more we learn about the mechanisms behind consciousness and free will, the easier it will be to settle them.

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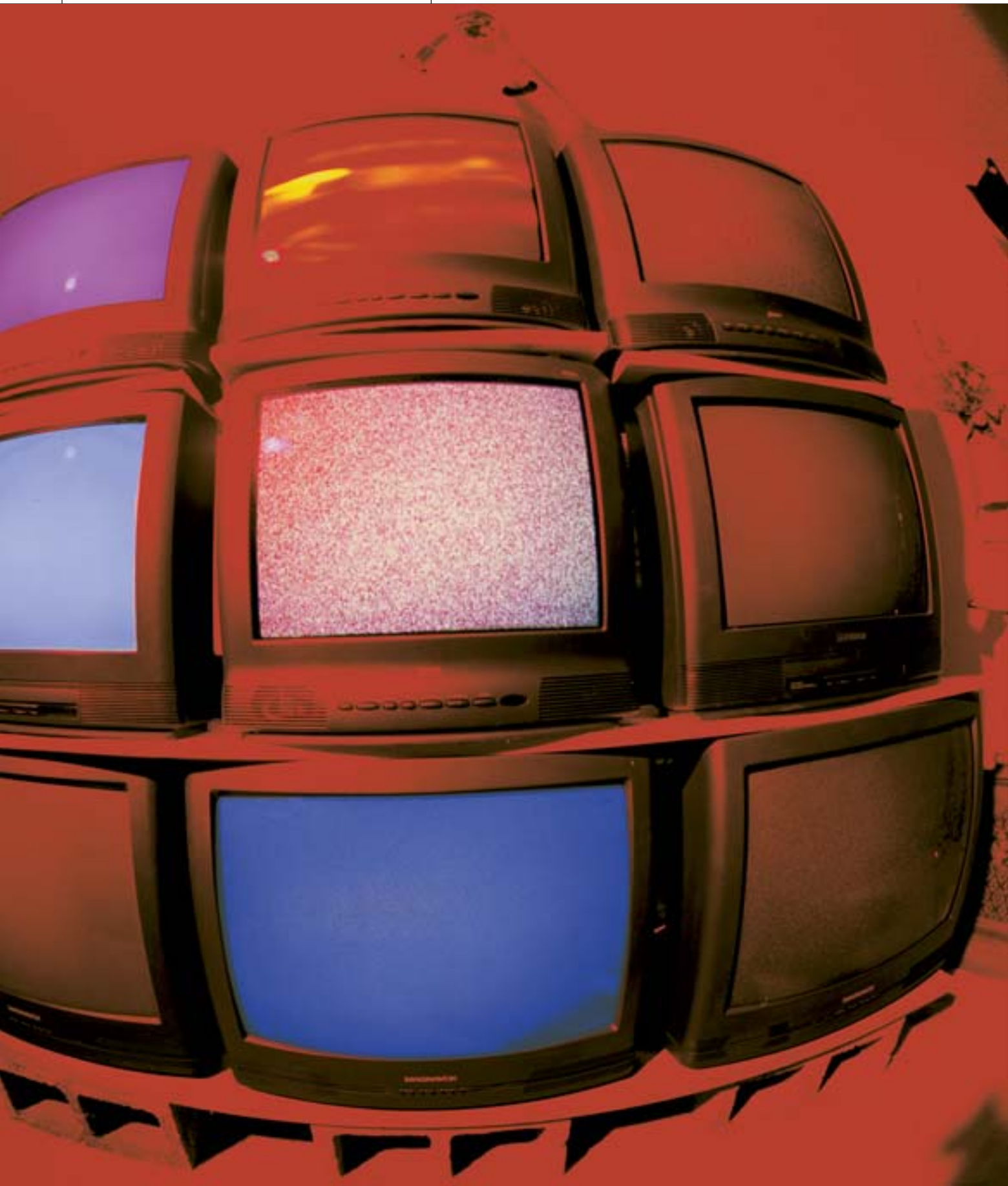
TELEVISION ADDICTION

IS NO MERE METAPHOR

By Robert Kubey and Mihaly Csikszentmihalyi
PHOTOGRAPHS BY CHIP SIMONS

Perhaps the most ironic aspect of the struggle for survival is how easily organisms can be harmed by that which they desire. The trout is caught by the fisherman's lure, the mouse by cheese. But at least those creatures have the excuse that bait and cheese look like sustenance. Humans seldom have that consolation. The temptations that can disrupt their lives are often pure indulgences. No one *has* to drink alcohol, for example. Realizing when a diversion has gotten out of control is one of the great challenges of life.







Excessive cravings do not necessarily involve physical substances. Gambling can become compulsive; sex can become obsessive. One activity, however, stands out for its prominence and ubiquity—the world’s most popular leisure pastime, television. Most people admit to having a love-hate relationship with it. They complain about the “boob tube” and “couch potatoes,” then they settle into their sofas and grab the remote control. Parents commonly fret about their children’s viewing (if not their own). Even researchers who study TV for a living marvel at the medium’s hold on them personally. Percy Tannenbaum of the University of California at Berkeley has written: “Among life’s more embarrassing moments have been countless occasions when I am engaged in conversation in a room while a TV set is on, and I cannot for the life of me stop from periodically glancing over to the screen. This occurs not only during dull conversations but during reasonably interesting ones just as well.”

Scientists have been studying the effects of television for decades, generally focusing on whether watching violence on TV correlates with being violent in real life [see “The Effects of Observing Violence,” by Leonard Berkowitz; *SCIENTIFIC AMERICAN*, February 1964; and “Communication and Social Environment,” by George Gerbner; September 1972]. Less attention has been paid to the basic allure of the small screen—the medium, as opposed to the message.

The term “TV addiction” is imprecise and laden with value judgments, but it captures the essence of a very real phenomenon. Psychologists and psychiatrists formally define substance dependence as a disorder characterized by criteria

that include spending a great deal of time using the substance; using it more often than one intends; thinking about reducing use or making repeated unsuccessful efforts to reduce use; giving up important social, family or occupational activities to use it; and reporting withdrawal symptoms when one stops using it.

All these criteria can apply to people who watch a lot of television. That does not mean that watching television, per se, is problematic. Television can teach and amuse; it can reach aesthetic heights; it can provide much needed distraction and escape. The difficulty arises when people strongly sense that they ought not to watch as much as they do and yet find themselves strangely unable to reduce their viewing. Some knowledge of how the medium exerts its pull may help heavy viewers gain better control over their lives.

A Body at Rest Tends to Stay at Rest

The amount of time people spend watching television is astonishing. On average, individuals in the industrialized world devote three hours a day to the pursuit—fully half of their leisure time and more than on any single activity save work and sleep. At this rate, someone who lives to 75 would spend nine years in front of the tube. To some commentators, this devotion means simply that people enjoy TV and make a conscious decision to watch it. But if that is the whole story, why do so many people experience misgivings about how much they view? In Gallup polls in 1992 and 1999, two out of five adult respondents and seven out of 10 teenagers said they spent too much time watching TV. Other surveys have consistently shown that roughly 10 percent of adults call themselves TV addicts.

To study people’s reactions to TV, researchers have undertaken laboratory experiments in which they have monitored the brain waves (using an electroencephalograph, or EEG), skin resistance or heart rate of subjects watching television. To track behavior and emotion in the normal course of life, as opposed to the artificial conditions of the lab, we have used the Experience Sampling Method (ESM). Participants carried a beeper, and we signaled them six to eight times a day, at random, over the period of a week; whenever they heard the beep, they wrote down what they were doing and how they were feeling using a standardized scorecard.

As one might expect, people who were watching TV when we beeped them reported feeling relaxed and passive. The EEG studies similarly show less mental stimulation, as measured by alpha brain-wave production, during viewing than during reading.

FAST FACTS

The Power of Television

- 1 >> Television is the world’s most popular pastime. On average, individuals in the industrialized world devote three hours a day to the pursuit—half their leisure time and more than any single activity except for work and sleep.
- 2 >> People who watch a lot of television can exhibit symptoms similar to substance dependence, including making repeated unsuccessful efforts to reduce use and even experiencing withdrawal when use stops.
- 3 >> Part of TV’s attraction springs from our biological “orienting response”—an instinctive visual or auditory reaction to any sudden or novel stimulus.

What is more surprising is that the sense of relaxation ends when the set is turned off, but the feelings of passivity and lowered alertness continue. Survey participants commonly reflect that television has somehow absorbed or sucked out their energy, leaving them depleted. They say they have more difficulty concentrating after viewing than before. In contrast, they rarely indicate such difficulty after reading. After playing sports or engaging in hobbies, people report improvements in mood. After watching TV, people's moods are about the same or worse than before.

Within moments of sitting or lying down and pushing the "power" button, viewers report feeling more relaxed. Because the experience of relaxation occurs quickly, people are conditioned to associate watching TV with rest and lack of tension. The association is positively reinforced because they remain relaxed throughout viewing, and it is negatively reinforced via the stress and dysphoric rumi-

ological "orienting response." First described by Ivan Pavlov in 1927, the orienting response is our instinctive visual or auditory reaction to any sudden or novel stimulus. It is part of our evolutionary heritage, a built-in sensitivity to movement and potential predatory threats. Typical orienting reactions include dilation of the blood vessels to the brain, slowing of the heart, and constriction of blood vessels to major muscle groups. Alpha waves are blocked for a few seconds before returning to their baseline level, which is determined by the general level of mental arousal. The brain focuses its attention on gathering more information while the rest of the body quiets.

In 1986 Byron Reeves of Stanford University, Esther Thorson of the University of Missouri and their colleagues began to study whether the simple formal features of television—cuts, edits, zooms, pans, sudden noises—activate the orienting response, thereby keeping attention on the screen.



(Most of the criteria of substance dependence can apply to people who watch a lot of TV.)

nation that occurs once the screen goes blank again.

Habit-forming drugs work in similar ways. A tranquilizer that leaves the body rapidly is much more likely to cause dependence than one that leaves the body slowly, precisely because the user is more aware that the drug's effects are wearing off. Similarly, viewers' vague learned sense that they will feel less relaxed if they stop viewing may be a significant factor in not turning the set off. Viewing begets more viewing.

Thus, the irony of TV: people watch far longer than they plan to, even though prolonged viewing is less rewarding. In our ESM studies the longer people sat in front of the set, the less satisfaction they said they derived from it. When signaled, heavy viewers (those who consistently watch more than four hours a day) tended to report on their ESM sheets that they enjoy TV less than did light viewers (less than two hours a day). For some, a twinge of unease or guilt that they aren't doing something more productive may also accompany and depreciate the enjoyment of prolonged viewing. Researchers in Japan, the U.K. and the U.S. have found that this guilt occurs much more among middle-class viewers than less affluent ones.

Grabbing Your Attention

What is it about TV that has such a hold on us? In part, the attraction seems to spring from our bi-

By watching how brain waves were affected by formal features, the researchers concluded that these stylistic tricks can indeed trigger involuntary responses and "derive their attentional value through the evolutionary significance of detecting movement. . . . It is the form, not the content, of television that is unique."

The orienting response may partly explain common viewer remarks such as: "If a television is on, I just can't keep my eyes off it," "I don't want to watch as much as I do, but I can't help it," and "I feel hypnotized when I watch television." In the years since Reeves and Thorson published their pioneering work, investigators have delved deeper. Annie Lang's research team at Indiana University has shown that heart rate decreases in subjects for four to six seconds after an orienting stimulus. In ads, action sequences and music videos, formal features frequently come at a rate of one per second, thus activating the orienting response continuously.

Lang and her colleagues have also investigated whether formal features affect people's memory of what they have seen. In one of their studies, participants watched a program and then filled out a score sheet. Increasing the frequency of edits—defined here as a change from one camera angle to another in the same visual scene—improved memory recognition, presumably because it focused at-

(Kicking the Habit)

Individuals or families who want to achieve better control of their TV viewing can try the following strategies:

RAISING AWARENESS. As with other dependencies, a first critical step is to become aware of how entrenched the viewing habit has become, how much time it absorbs and how limited the rewards of viewing actually are. One way to do this is to keep a diary for a few days of all programs viewed. The diary entries might rate the quality of the experience, denoting how much the viewer enjoyed or learned from various programs.

PROMOTING ALTERNATIVE ACTIVITIES. As soon as they finish dinner, many families rush to the television. To supplant viewing with other activities, it may prove helpful to make a list of alternatives and put it on the fridge. Instead of reflexively plopping down in front of the tube, those interested in reducing their viewing can refer to the list.

EXERCISING WILLPOWER. Viewers often know that a particular program or movie-of-the-week is not very good within the first few minutes, but instead of switching off the set, they stick with it for the full two hours. It is natural to keep watching to find out what happens next. But once the set is off and people have turned their attention to other things, they rarely care anymore.

ENFORCING LIMITS. A kitchen timer can come in handy when setting time limits, especially with video games. When it rings, the kids know to stop. Some parents find that this works much better than announcing the deadline themselves. The children take the bell more seriously.

BLOCKING CHANNELS/V-CHIP. Television sets now come equipped with microchips that can be used to prevent viewing of violent shows. In addition, electronic add-on devices can count how many hours each family member has viewed and block access beyond a particular quota.

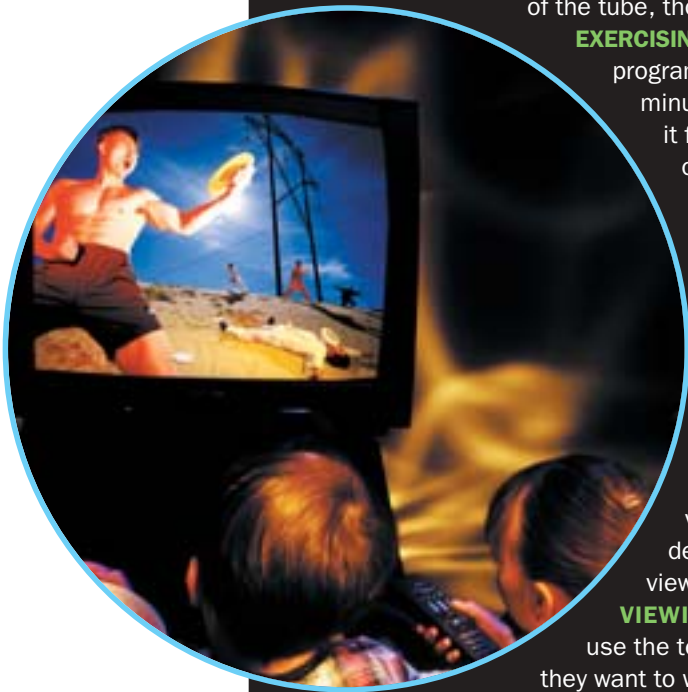
VIEWING SELECTIVELY. Rather than channel-surfing, people can use the television listings ahead of time to choose which programs they want to watch.

USING THE VCR. Instead of watching a program, record it for later viewing. Many people never return to much of the material they have taped.

GOING COLD TURKEY. Many families have succeeded in reducing viewing by limiting the household to one set and placing it in a remote room of the house or in a closet. Others end their cable subscriptions or jettison the set altogether.

SUPPORTING MEDIA EDUCATION. Schools in Canada and Australia, as well as in an increasing number of states in the U.S., now require students to take classes in media education. These courses sharpen children's ability to analyze what they see and hear and to make more mindful use of TV and other media.

—R.K. and M.C.



tention on the screen. Increasing the frequency of cuts—changes to a new visual scene—had a similar effect but only up to a point. If the number of cuts exceeded 10 in two minutes, recognition dropped off sharply.

Producers of educational television for children have found that formal features can help learning. But increasing the rate of cuts and edits

eventually overloads the brain. Music videos and commercials that use rapid intercutting of unrelated scenes are designed to hold attention more than they are to convey information. People may remember the name of the product or band, but the details of the ad itself float in one ear and out the other. The orienting response is overworked. Viewers still attend to the screen, but they feel tired

and worn out, with little compensating psychological reward. Our ESM findings show much the same thing.

Sometimes the memory of the product is very subtle. Many ads today are deliberately oblique: they have an engaging story line, but it is hard to tell what they are trying to sell. Afterward you may not remember the product consciously. Yet advertisers believe that if they have gotten your attention, when you later go to the store you will feel better or more comfortable with a given product because you have a vague recollection of having heard of it.

The natural attraction to television's sound and light starts very early in life. Dafna Lemish of Tel Aviv University has described babies at six to eight weeks attending to television. We have observed slightly older infants who, when lying on their backs on the floor, crane their necks around 180 degrees to catch what light through yonder window breaks. This inclination suggests how deeply rooted the orienting response is.

"TV Is Part of Them"

That said, we need to be careful about overreacting. Little evidence suggests that adults or children should stop watching television altogether. The problems come from heavy or prolonged viewing.

The Experience Sampling Method permitted us to look closely at most every domain of everyday life: working, eating, reading, talking to friends, playing a sport, and so on. We wondered whether heavy viewers might experience life differently than light viewers do. Do they dislike being with people more? Are they more alienated from work? What we found nearly leaped off the page at us. Heavy viewers report feeling significantly more anxious and less happy than light viewers do in unstructured situations, such as doing nothing, daydreaming or waiting in line. The difference widens when the viewer is alone.

Subsequently, Robert D. McIlwraith of the University of Manitoba extensively studied those who called themselves TV addicts on surveys. On a measure called the Short Imaginal Processes Inventory (SIPI), he found that the self-described addicts are more easily bored and distracted and have poorer attentional control than the non-addicts. The addicts said they used TV to distract themselves from unpleasant thoughts and to fill time. Other studies over the years have shown that heavy viewers are less likely to participate in community activities and sports and are more likely to be obese than moderate viewers or nonviewers.

The question that naturally arises is: In which direction does the correlation go? Do people turn to TV because of boredom and loneliness, or does TV viewing make people more susceptible to boredom and loneliness? We and most other researchers argue that the former is generally the case, but it is not a simple case of either/or. Jerome L. Singer and Dorothy Singer of Yale University, among others, have suggested that more viewing may contribute to a shorter attention span, diminished self-restraint and less patience with the normal delays of daily life. More than 25 years ago psychologist Tannis M. MacBeth Williams of the University of British Columbia studied a mountain community that had no television until cable finally arrived. Over time, both adults and children in the town became less creative in problem solving, less able to persevere at tasks, and less tolerant of unstructured time.

To some researchers, the most convincing parallel between TV and addictive drugs is that people experience withdrawal symptoms when they cut back on viewing. Nearly 40 years ago Gary A. Steiner of the University of Chicago collected fascinating individual accounts of families whose TV set had broken—this back in the days when households generally had only one: "The family walked around like a chicken without a head." "It was terrible. We did nothing—my husband and I talked." "Screamed constantly. Children bothered me, and my nerves were on edge. Tried to interest them in games, but impossible. TV is part of them."

In experiments, families have volunteered or been paid to stop viewing, typically for a week or a month. Many could not complete the period of abstinence. Some fought, verbally and physically. Anecdotal reports from some families that have tried the annual "TV turn-off" week in the U.S. tell a similar story.

If a family has been spending the lion's share of its free time watching television, reconfiguring itself around a new set of activities is no easy task. Of course, that does not mean it cannot be done



(The Authors)

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or that all families implode when deprived of their set. In a review of these cold-turkey studies, Charles Winick of the City University of New York concluded: "The first three or four days for most persons were the worst, even in many homes where viewing was minimal and where there were other ongoing activities. In over half of all the households, during these first few days of loss, the regular routines were disrupted, family members had difficulties in dealing with the newly available time, anxiety and aggressions were expressed.... People living alone tended to be bored and irritated.... By the second week, a move toward adaptation to the situation was common." Unfortunately, researchers have yet to flesh out these anecdotes; no one has systematically gathered statistics in a study on the prevalence of these withdrawal symptoms.

Even though TV does seem to meet the criteria for substance dependence, not all researchers would go so far as to call it addictive. McIlwraith said in 1998 that "displacement of other activities by television may be socially significant but still fall short of the clinical requirement of significant impairment." He argued that a new category of "TV addiction" may not be necessary if heavy viewing stems from conditions such as depression and social phobia. Nevertheless, whether or not we formally diagnose someone as TV-dependent, millions of people sense that they cannot readily control the amount of television they watch.

Slave to the Computer Screen

Although much less research has been done on video games and computer use, the same principles often apply. The games offer escape and distraction; players quickly learn that they feel better when playing, and so a kind of reinforcement loop develops. The obvious difference from television, however, is the interactivity. Many video and computer games minutely increase in difficulty along with the increasing ability of the player. One can search for months to find another tennis or chess player of comparable ability, but programmed games can immediately provide a near-perfect match of challenge to skill. They offer the psychic pleasure—what one of us (Csikszentmihalyi) has called "flow"—that accompanies increased mastery of most any human endeavor. On the other hand, prolonged activation of the orienting response can wear players out. Kids report feeling tired, dizzy and nauseated after long sessions.

In 1997, in the most extreme medium-effects case on record, 700 Japanese children were rushed to the hospital, many suffering from "optically





stimulated epileptic seizures” caused by viewing bright flashing lights in a Pokémon cartoon broadcast on Japanese TV. Seizures and other untoward effects of video games are significant enough that software companies and platform manufacturers now routinely include warnings in their instruction booklets. Parents have reported to us that rapid movement on the screen has caused motion sickness in their young children after just 15 minutes of play. Many youngsters, lacking self-control and experience (and often supervision), continue to play despite these symptoms.

Lang and Shyam Sundar of Pennsylvania State University have been studying how people respond to Web sites. Sundar has shown people multiple versions of the same Web page, identical except for the number of links. Users reported that more links conferred a greater sense of control and engagement. At some point, however, the number of links reached saturation, and adding more of them simply turned people off. As with video games, the ability of Web sites to hold the user’s attention seems to depend less on formal features than on interactivity.

For a growing number of people, the life they lead online may often seem more important, more immediate and more intense than the life they lead face-to-face. Maintaining control over one’s media habits is more of a challenge today than it has ever been. TV sets and computers are everywhere. But the small screen and the Internet need not interfere with the quality of the rest of one’s life. In its easy provision of relaxation and escape, television can be beneficial in limited doses. Yet when the habit interferes with the ability to grow, to learn new things, to lead an active life, then it does constitute a kind of dependence and should be taken seriously.

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Sussing Out STRESS

Chronic stress makes people sick. But how? And how might we prevent those ill effects?

By Hermann Englert

R

oad rage, heart attacks, migraine headaches, stomach ulcers, irritable bowel syndrome, hair loss among women—stress is blamed for all those and many other ills. Nature provided our prehistoric ancestors with a tool to help them meet threats: a quick activation system that focused attention, quickened the heartbeat, dilated blood vessels and prepared muscles to fight or flee the bear stalking into their cave. But we, as modern people, are subjected to stress constantly from commuter traffic, deadlines, bills, angry bosses, irritable spouses, noise, as well as social pressure, physical sickness and mental challenges. Many organs in our bodies are consequently hit with a relentless barrage of alarm signals that can damage them and ruin our health.





Daily pressures raise our stress level, but our ancient stress reactions—fight or flight—do not help us survive this kind of tension.

What exactly happens in our brains and bodies when we are under stress? Which organs are activated? When do the alarms begin to cause critical problems? We are only now formulating a coherent model of how ongoing stress hurts us, yet in it we are finding possible clues to counteracting the attack.

The Road to Overload

In recent decades, researchers have identified many parts of the brain and body that contribute importantly to the stress reaction—the way we respond to external stressors. These regions process

CRH), a messenger compound that unleashes the stress reaction.

CRH was discovered in 1981 by Wylie Vale and his colleagues at the Salk Institute for Biological Studies in San Diego and since then has been widely investigated. It controls the stress reaction in two ways.

Primarily, it reaches organs via the so-called long arm—the hormone signal pathway from the hypothalamus to the pituitary gland in the brain and to the adrenal glands on the kidneys. This long arm is also known as the hypothalamus-pituitary-adrenal axis.

When an emergency ends, the stress system must turn off so organs can recover. But constant anxiety keeps the system on, and organs never relax.

sensory and emotional information and communicate with a wide network of nerves, organs, blood vessels and muscles, reallocating the body's energy reserves so that we can assess and respond to situations.

When stress begins, a small area deep in the brain called the hypothalamus pulls the strings. It contains several different nuclei, or collections of neurons, that undertake various tasks. They regulate sleep and appetite, for example, and the balance among different hormones. The most critical collection of neurons is the paraventricular nucleus, which secretes corticotropin-releasing hor-

The arrival of CRH tells the pituitary to release adrenocorticotrophic hormone (ACTH) into the bloodstream. ACTH, in turn, activates the adrenal glands to release glucocorticoid hormones into the blood. Levels of glucocorticoids typically follow a daily rhythm: high in the early morning, lower late in the day. One of their most important tasks is to increase glucose in the blood to provide energy for muscles and nerves. They also control glucose metabolism and the sleep-wake cycle. Because hormones regulate such critical functions, their levels have to be precisely controlled, and they are thus subject to a feedback mechanism in the hypothalamus, which can quickly return the system to lower values.

CRH also makes its effects felt by acting on the “short arm” pathway. A small region in the brain stem termed the locus coeruleus functions as a kind of neural relay station. It links the CRH-producing brain regions with the autonomic nervous system, which governs the ongoing physiological processes we never have to think about, such as breathing, blood pressure, digestion and so on.

The stress response system produces positive feedback to strengthen its own action when needed, but when daily stress builds up, it can become unnecessarily intense and sustained. Whether the response is appropriate or not depends on cells that coat the pituitary gland and other parts of the system. CRH sends signals into these cells by docking with type 1 receptor molecules on the cells' membranes. Researchers at the Salk Institute and at the Max Planck Institute of Psychiatry in Munich bred mice in which type 1 receptors were lacking. Even when these mice were repeatedly ex-

FAST FACTS

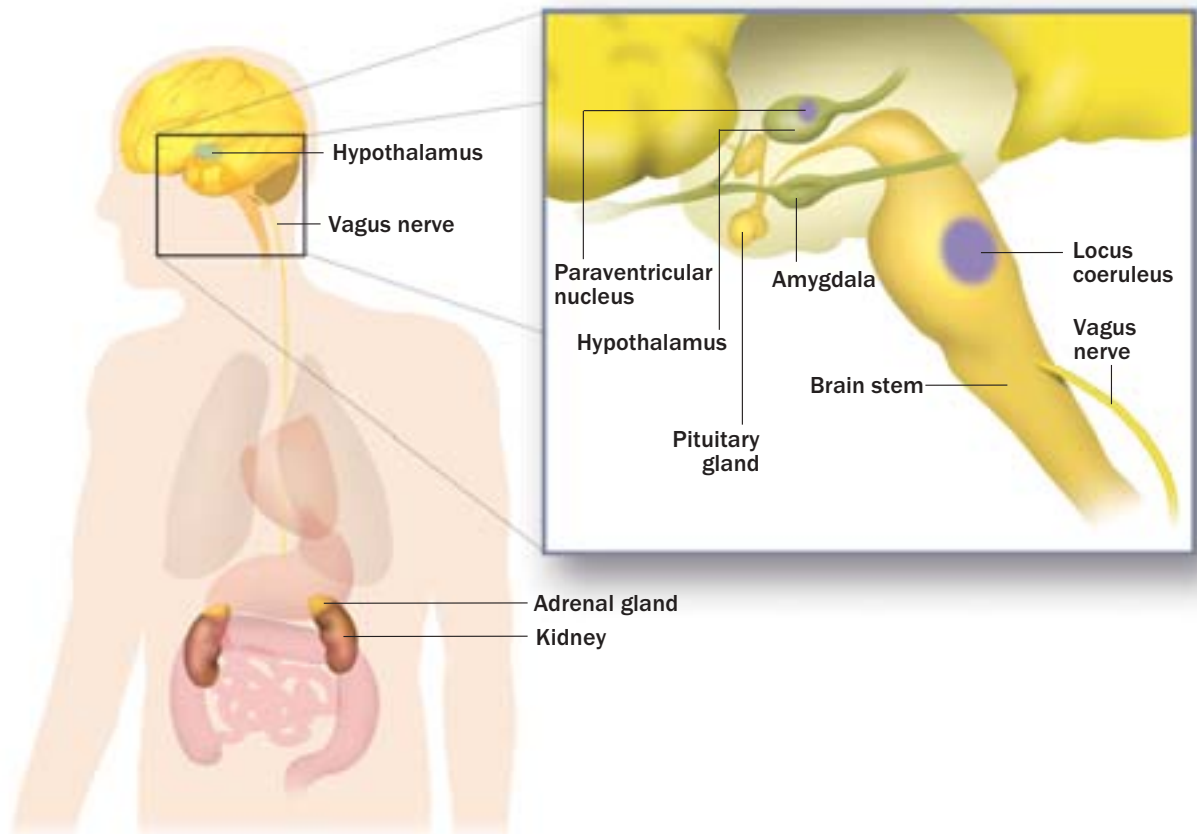
How Stress Harms the Body

1 >> Our stress system can quickly ramp up the heart, lungs and other organs so that we are ready to fight or flee sudden threats. But when we face unending stressors from modern life, the system can bombard our organs with relentless alarm signals that can wear down our organs and our health.

2 >> When vision, hearing or thoughts indicate “stress,” the hypothalamus initiates a chain reaction involving the amygdala and the pituitary and adrenal glands, carried out by nerve impulses and a cascade of hormones, chief among them CRH, ACTH and glucocorticoids.

3 >> If researchers can determine exactly which receptor cells in the brain and glands propagate stress signals, they may be able to design drugs that can interfere, sparing organs the strain that stress creates.

Turning On



Stress signals change the physiological states of many organs, including the heart, kidneys, stomach and reproductive system, as well as muscles. The hypothalamus receives sensory stressors (such as seeing a bear) from nerves. The locus coeruleus (*blue spot*) delivers emotional stressors (such as worrying about the bear's teeth) from the amygdala to the paraventricular nu-

cleus. That structure makes corticotropin-releasing hormone (CRH), the most important stress hormone, which tells the pituitary gland to send impulses via nerves such as the vagus and to release other hormones into the bloodstream. Those hormones activate the adrenal glands, which raise blood pressure and increase glucose levels in the blood, providing energy to fight or flee.

posed to stressful situations, levels of certain stress hormones in their blood never rose above normal. The animals obviously felt less stressed. Perhaps drugs that suppress the effects of CRH on these receptors might reduce stress levels in harried humans, too.

Organs Break Down

Our new knowledge of the stress system provides strong clues as to how stress can make us sick and how we might counteract its effects. For a mouse or human, any activation of the stress system counts as an extraordinary event—and when the emergency ends, the system must quickly be turned off so that the affected organs can recov-

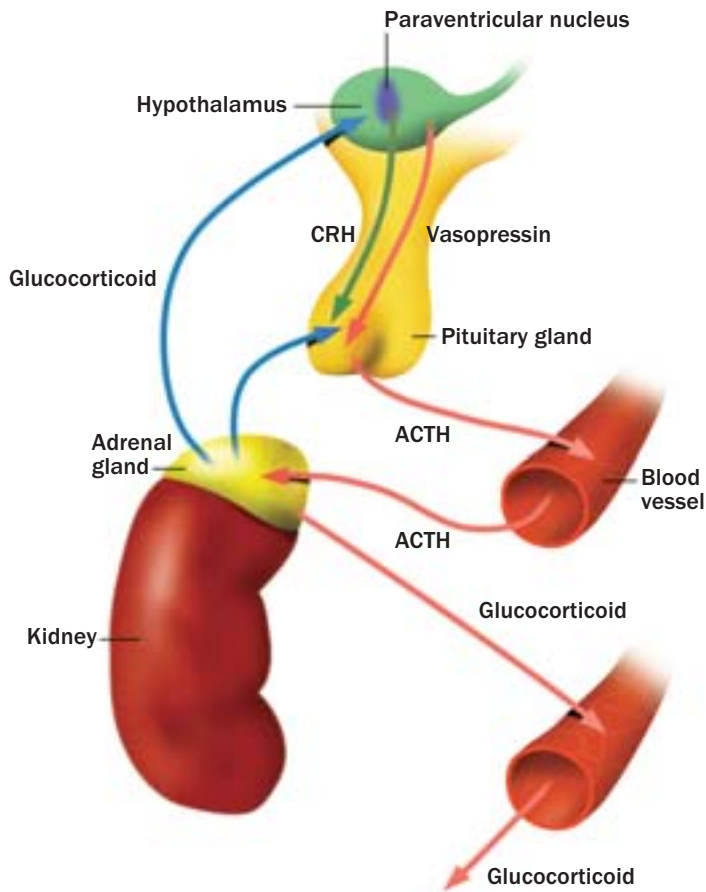
er. But when external circumstances stimulate the stress system repeatedly, it never stops reacting, and organs are never allowed to relax.

Such chronic strain leaves many tissues vulnerable to damage. The reproductive organs, for example, often become less effective. Research indicates that male and female athletes and ballet dancers who subject themselves to great physical demands over many years produce fewer sperm or egg cells. Male testosterone levels decline, and fe-

(The Author)

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Tuning In



The hypothalamus runs the “long arm” of the stress system by secreting the hormone CRH. CRH flows through veins (green arrow) to the pituitary, which in turn releases the hormone ACTH into the blood. ACTH stimulates the adrenal glands to produce glucocorticoid hormones, which put the body on alert. In acute stress, the hypothalamus secretes vasopressin as well, to further activate the adrenals. The system regulates itself down after a threat is over via a negative feedback loop (blue arrows), in which glucocorticoids bathe both the hypothalamus to suppress CRH secretion and the pituitary to suppress ACTH. But daily stress may endlessly activate the system.

male menstrual cycles may become disordered or even cease.

Anorexia and long-term fasting have similar harmful effects on fertility. Both allow the level of CRH in the brain to increase. Anorexic patients have higher late-day levels of the stress hormone glucocorticoid cortisol in their plasma and urine than healthy people do. And when their pituitaries are artificially stimulated with CRH, anorexics se-

crete less of the hormone that mediates the stress response—evidence that their hypothalamus-pituitary-adrenal axis is hyperactive.

Excessive CRH from chronic stress also reduces the body’s secretion of growth hormone, as well as its production of the substance that mediates the effects of growth hormone on organs. Children who are under great stress therefore grow more slowly. Among adults, the growth of muscles and bones and the metabolism of fat are hindered.

One of the most prevalent physiological effects of stress involves the stomach and intestines. When the hypothalamus-pituitary-adrenal axis is too active and levels of CRH in the brain are simultaneously too high, signals on the vagus nerve are blocked. This nerve, a major thoroughfare of the autonomic nervous system, controls contractions of the stomach and digestive tract. (It also sends nerve impulses to the heart and motor muscles.) A classic example of a stress-induced reaction by these organs is the shutdown of digestion after surgery. Some studies suggest that irritable bowel syndrome, a widespread complaint, is caused by too much CRH.

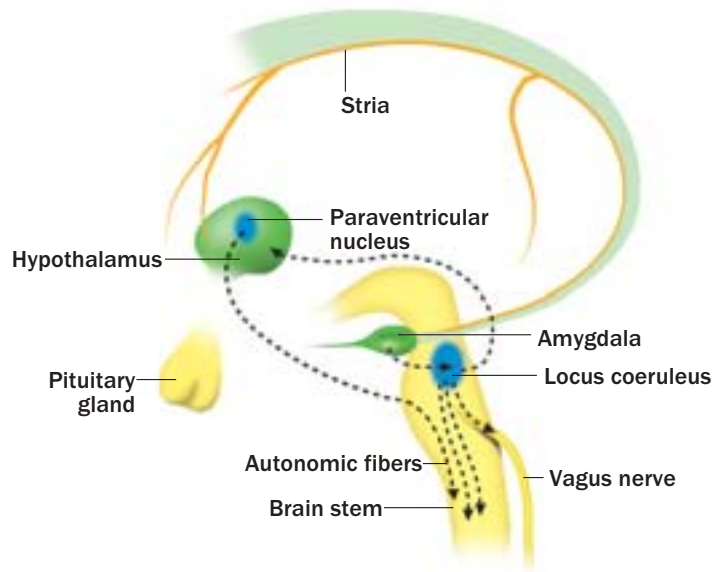
Other recent investigations find that victims of sexual assault or abuse, who almost always suffer some level of psychological damage even years after the abuse occurred, frequently also experience digestive disorders. In these same people, most of them young women, the hypothalamus-pituitary-adrenal axis is hyperactive. If it remains so for a long time, the metabolism of carbohydrates changes. Their body fat redistributes: fat deposits under the skin shift to the abdomen. Cells in their body may stop taking up the sugar glucose in response to insulin, a condition that can lead to diabetes in certain people.

An overactive hypothalamus-pituitary-adrenal axis can also cause symptoms that mirror those of mental illness. Indeed, the latest pharmacological research shows that too much CRH plays a role in mental disorders. Many depression patients, for example, have far too much cortisol in their blood. And the glucocorticoids in their blood are unable to suppress activity in the hypothalamus-pituitary-adrenal axis. In addition, they have too much CRH in their cerebrospinal fluid. Depressed people who commit suicide often have fewer CRH receptors in their brain’s frontal cortex, an indication that, to defend itself against too much CRH, the brain reduces its susceptibility to the hormone.

The hypothalamus-pituitary-adrenal axis may also enhance phobias and panic attacks. [For more on the mental and physical processes of anxiety,

Stressing Out

A group of neurons in the brain stem, called the locus coeruleus, coordinates the “short arm” of the stress system along multiple nerve pathways (black). It signals the hypothalamus, which contacts autonomic nerve fibers in the brain stem. Other locus coeruleus neurons directly trigger stress responses in organs and glands through autonomic nerve fibers extending through the body. In sending its alerts, the locus coeruleus gets emotional inputs from the amygdala and the stria, which also reach the hypothalamus. Constant anxiety, frequent fear or aggression may cause nerves to fire unendingly, causing wear on the brain and body.



Drugs that suppress the reaction of receptor cells on the pituitary gland to the hormone CRH could reduce stress levels in harried humans.

see “Fear Not,” on page 62.] Here again, too much CRH is present, causing the brain to be overactive. When CRH is injected into the brains of laboratory animals, they exhibit extreme fear. Patients with panic disorders such as agoraphobia (fear of open places) or claustrophobia (fear of confined spaces) secrete too little ACTH after they are given CRH as a drug. Clinical studies are under way in Europe to see whether patients with panic disorders can be helped by drugs that suppress the type 1 CRH receptors. Eventually, it is hoped, researchers will find ways to interrupt the overstimulated chain of command.

Measuring the Risk

Stress can make us sick, but not all stress is the same. A certain baseline level, called positive stress, is even desirable, because it keeps us mentally and physically ready to act and to perform well. But when are we at risk? There is no generally accepted answer to this question. We do not know how much workplace noise or how many broken relationships our stress systems can withstand. Yet an expanding portfolio of research shows that chronic stress is compromising our organs and bodies. Although we no longer face the bear in the

cave, we may be in more dire straits, dealing with many more insidious stressors that are always tearing at us.

Before we can reduce this threat, we must learn how to measure each person’s stress level. Physiologists are working on a set of parameters—such as CRH levels—that would be used to evaluate all the organs involved in the stress reaction. Once we know an individual is being harmed, then we must reduce the levels of stress he or she faces.

That, of course, may not always be possible in our complex world. So we must also develop therapies that prevent our stress system from ceaselessly racing. CRH, ACTH, their receptors and the hypothalamus-pituitary-adrenal axis are all possible targets. Researchers are busily investigating them—free, one hopes, of the stress that often accompanies important scientific pursuits.

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A black and white photograph of a stone building with a window and a textured foreground. The image is used as a background for the text.

FEAR NOT

Anxieties can become strongly etched into the brain. But don't worry—researchers may find ways to erase them

By Rüdiger Vaas



It is a remarkable achievement that today, at least in developed countries, we seldom encounter any natural, fear-evoking situations. We are not likely to meet up with snakes or crocodiles or to find ourselves without shelter during a storm. But in our efforts to command nature and our fellow human beings, we have created new hazards: highways and greenhouse gases, machine guns and bioterrorism, and the social pressures of failure and embarrassment. That these dangers are not immediate enough to evoke real fear for most people is scarcely a blessing; the anxieties of modern life can be debilitating. “Perhaps man is the most fearful of all creatures,” comments Irenäus Eibl-Eibesfeldt, anthropologist emeritus at the Max Planck Institute of Behavioral Physiology in Seewiesen, Germany, “because along with such elementary fears as those of predators, he also suffers from an intellectually grounded fear of existence.”

More intellectual work, however, might free us from this burden. Research into how the brain transmits, sustains, and remembers fears and anxieties is providing clues about how to control or

even eliminate them. Understanding the demon will help us overcome it.

Where the Nightmare Begins

Strangely, flat-out fear may be easier to handle than anxiety. We see a vicious dog running at us, our brain sounds alarms, our heart and lungs race, and we fight or flee. As scary as such an experience is, it comes to a clear end, and the body and brain return to their normal states. Anxiety is much more insidious and can be more harmful over time. Many people even enjoy playing with fear by reading ghost stories, watching horror films or participating in extreme sports. But anxiety can dampen the joy of discovery, spoil the fun of games, inhibit initiative and creativity, and, in greater doses, ruin an individual’s health.

Other than addictions, anxiety disorders are the most common of all mental problems. More than 10 percent of Americans and Europeans suffer from them. Most common are phobias—exaggerated fears of specific things such as spiders or snakes and situations such as heights or enclosed spaces. Common, too, are compulsive feelings of dread, whereby people can describe what makes them anxious but not why.

Recent studies hint that anxiety disorders and even general anxiousness have a genetic component, although a person’s environment certainly has the most influence. Identical twins—even those who grow up separately—share more fears than fraternal twins do. There is, of course, no single gene for fear; many genes are involved in interactions with neurotransmitters and their receptors. The genes that command the biological clock, which is responsible for an organism’s inner rhythms, also appear to contribute in a way we do not yet understand.

Scientists have already succeeded in breeding fearfulness and fearlessness into rats. Normally, rats will not remain long in an open area; they have an instinctive fear of places that do not offer shelter from predators. But just a few generations of inbreeding and selection can result in rats that differ markedly in the length of time they will loiter in an open field.

The neurobiological bases of anxiety and fear are now relatively well described. No single region of the brain is solely responsible for creating anxiety and awareness of it. Rather fear springs from a collaboration among many brain areas.

Imaging experiments show that parts of the temporal lobes, on the left and right sides of the brain, experience greatly increased blood flow not just during panic attacks but from everyday anxi-

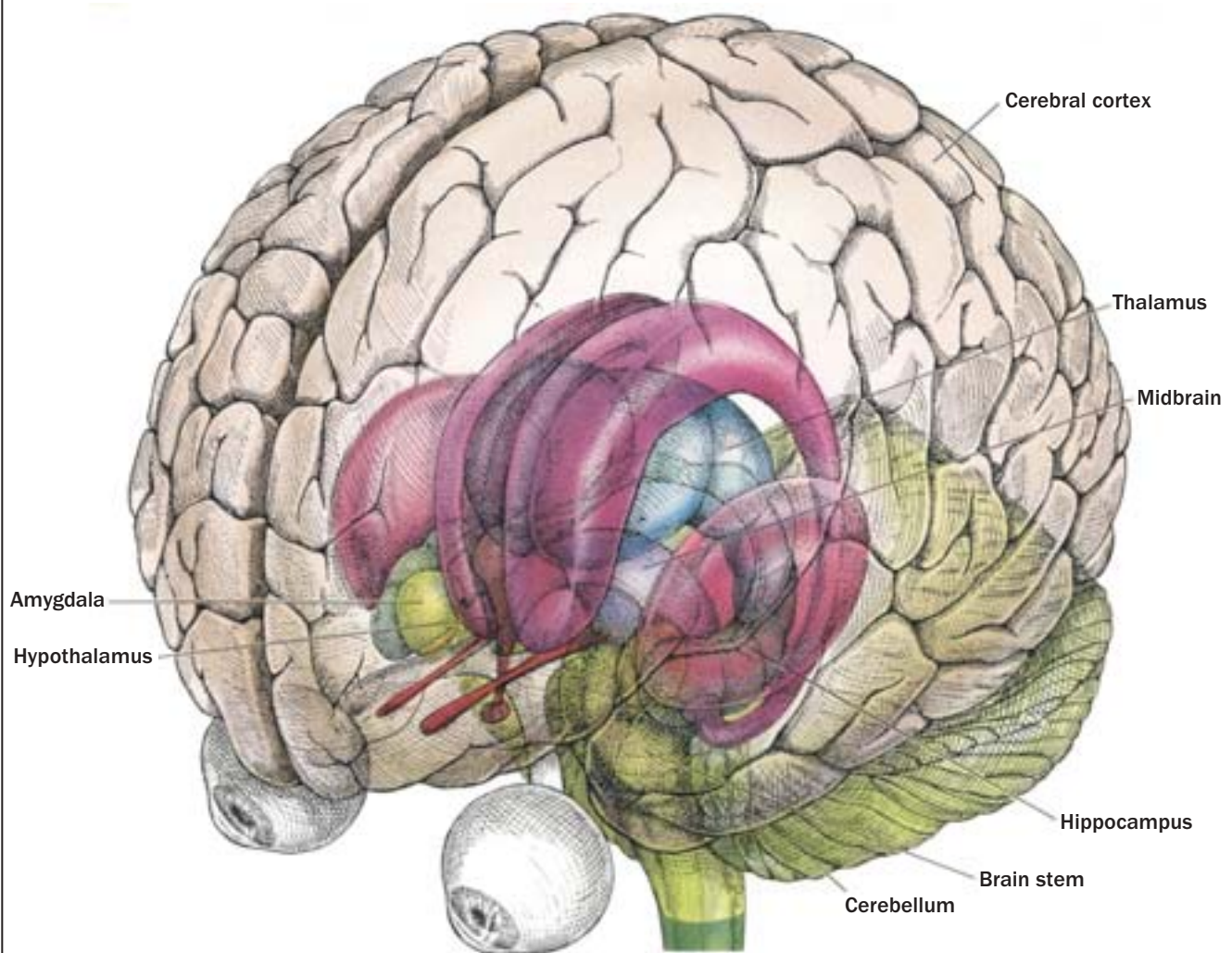
(A Brief History of Fear)

The ancient Greeks connected fear to concrete objects. For Aristotle and Plato, fear was above all a physical reaction. Aristotle does not even mention fear in his *De Anima* (“Of the Soul”). And the etymology of the word “anxiety” (*angst* in German, *anxiété* in French) is firmly rooted in bodily phenomena, springing from the Greek *agchein* (“to strangle”) and the Latin *angere* (“to strangle or confine”). But what Germans call *weltangst*—loosely, “social anxiety” in English—is a more recent phenomenon, perhaps originating in the Roman world.

Religions have consistently promised liberation from fear, although they ironically work to arouse fear, too: consider the Last Judgment, images of hell and the threat of eternal purgatory. Theologian Saint Augustine distinguished between “lower” fears, such as that of being punished, and the more exalted fear of guilt in the eyes of God.

Anxiety played no role in the Renaissance, which placed its faith in progress and rationality. This attitude changed in the 19th century, when philosopher Søren Kierkegaard considered existential angst a characteristic of human thought. He hoped—by his “leap of faith”—to overcome it. “What makes fear fearful is its in-the-worldness itself,” stated Martin Heidegger after him. The *Dasein*—the “person”—fears for his nonbeing, a “being to death.” For Jean-Paul Sartre, anxiety is a “quality of our existence,” a precondition for freedom, something to which people are condemned. For Sartre and perhaps other philosophers today, angst is not necessarily bad, because it can also lead a person to his “real self.” —R.V.

Fighting off a vicious dog is scary, but the event ends and the body and brain return to normal. Anxiety is much more insidious and harmful over time.



Danger Rears Its Head

When we perceive a threat, the thalamus integrates sensory and motor information and sends it to the amygdala. The thalamus also alerts the amygdala to thoughts about danger that arise in areas of the cerebral cortex responsible for consciousness. The amygdala, in turn, sends signals back that can influence our awareness and even memory of danger. The amygdala's closely connected central nu-

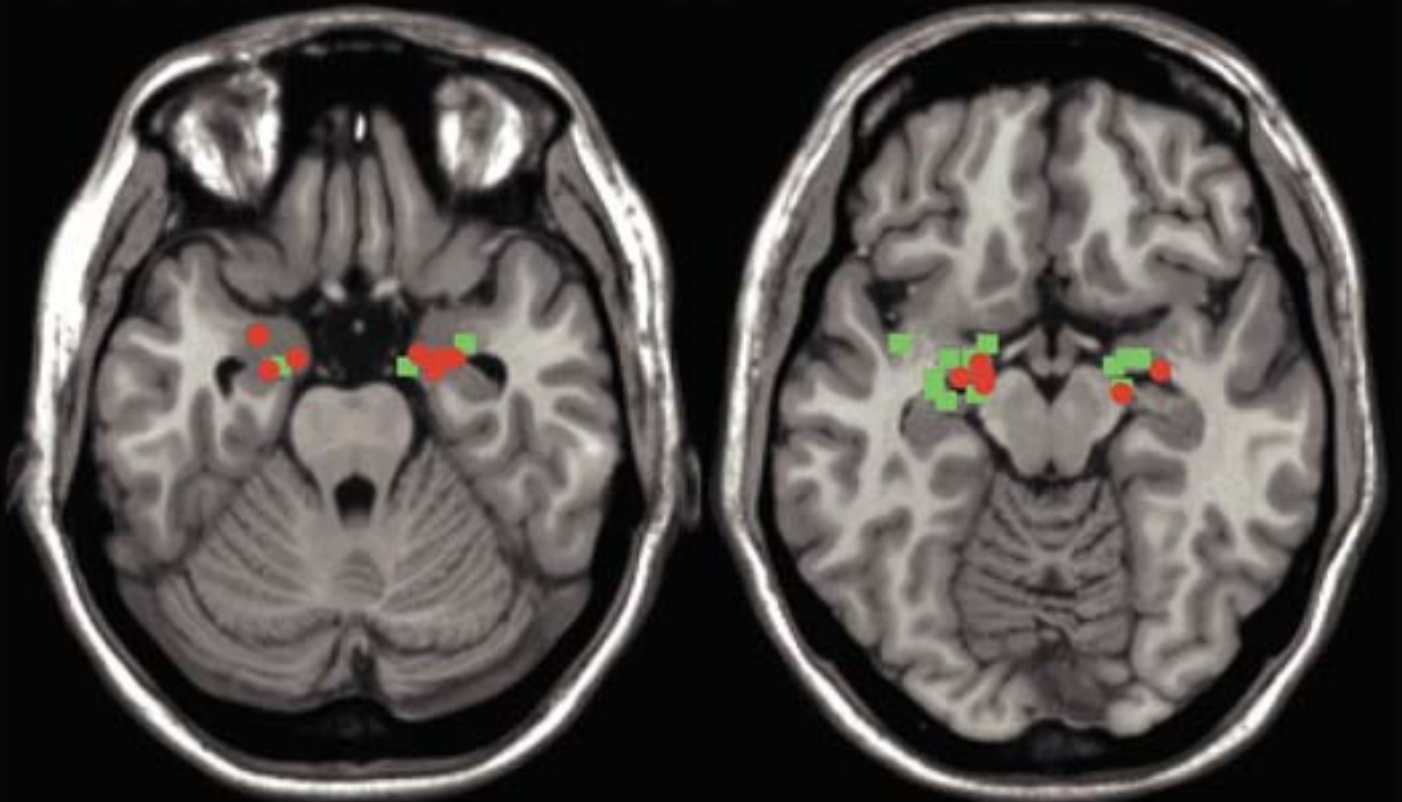
cleus sends commands to the hypothalamus, which causes stress hormones to be released that raise blood pressure and ready the body to defend itself. The central nucleus also instructs the brain stem and central midbrain, which control the fear reaction and fear paralysis. The amygdala's lateral and basal nuclei control behavioral changes, such as changing directions during flight.

CAROL DONNER

ety. And when researchers electrically stimulate the lobes in volunteers, the subjects report feelings of anxiety. The underside of the prefrontal cortex—a region at the very front of the brain responsible for higher-level functioning—is active as

well. Damage to the prefrontal cortex affects not only a person's feelings but also his or her ability to recognize emotions in others. The prefrontal cortex is not complete at birth; it takes another seven to 12 months to mature. This may be why

Emotionally intense experiences may “scar” cerebral tissue in ways that produce anxiety disorders. Drugs could prevent the scars from forming.



Using functional magnetic resonance imaging of a lower (left) and higher (right) cross section of the brain, scientists have shown that both the left and right sides of the amygdala are active when processing facial expressions of fright (green) as well as during conditioned fear (red).

The information processing during both situations is quite different, however. Expressions of fright produce activity more in the left side of the upper amygdala than in the right side, whereas the response to conditioned fear is more evenly distributed.

fear of strangers begins in infants at just this time—they are incapable of experiencing this type of anxiety in their first six months.

The hypothalamus, a part of the midbrain, is also important and is currently a target for psychiatric drugs. It controls the hormone system and influences the sympathetic nervous system, which together marshal the body’s resources to respond to threats. But the same network can disable the body’s reactions. Being “paralyzed by fear” may have had evolutionary advantages, keeping prehistoric humans perfectly still so that predators did not notice them or react to their movements.

The most active region of the brain during fear and anxiety is the amygdala, just below the temporal lobe. When researchers stimulate it electrically, levels of the hormone cortisol increase, as do

a subject’s physical signs of fear. The amygdala is especially active during dream sleep, a probable cause for anxiety dreams and nightmares. And when the amygdala is injured, feelings of anxiety diminish but cognitive functions remain much the same. Interestingly, patients who are born with amygdala damage cannot recognize fear in the faces of others.

Learning Fear, then Erasing It

Infants, for their part, do not react with fear when shown pictures of threatening faces. But while still young, they come to know that malevolent faces usually lead to malevolent words or deeds. The fact that memories of fear can work unconsciously was first recognized in the early 1900s by Edouard Claparède. He was a psychol-

ANDREW CALDER

ogist at Geneva University who later founded the Jean Jacques Rousseau Institute, which became a famous educational center for leading psychologists. Claparède was treating a woman who, because of a brain injury, could no longer process new information. He had to introduce himself to her at each appointment. One time he entered the room with a thumbtack hidden in the palm of his hand and shook hands with her. When she arrived for her next visit, she refused to shake hands, although she could not provide any reasonable explanation for why. Claparède concluded that an unconscious memory must have warned her.

In recent years, scientists have conducted thorough research into how fear-linked situations are stored in our memories. When rats, for example, hear a tone and are then given an electric shock, they soon begin to react with fear to the sound alone. The central nucleus of the amygdala seems to be key to storing fear memories.

Remarkably, the hippocampus in the temporal lobe—one of the most important regions for conscious memories of facts—plays no role in standard conditioning (for example, in tests in which rats learn to associate stimuli that are neither threatening nor desirable). But it becomes influential when the context of the stimulus matters. In experiments, if a neutral tone is accompanied by a special light, then when the light alone is shown, a reaction is set off in the hippocampus.

ation of more receptor molecules on these neurons that are tailored to receive a certain chemical stimulus. When these receptors are blocked in lab tests, however, fear conditioning no longer functions, so it might be possible to design drugs that control or prevent fears from being laid down in the brain. In addition, as neurons learn fear, they synthesize particular proteins, and the process continues even after the conditioning experience stops. Scientists have determined that they can erase fear reactions in lab animals that were learned as much as two

(The Word Is Equal to the Sword)

We are capable of learning fear in a strictly verbal sense—without any direct, personal experience. Subjects in one experiment were told that they would receive a slight electrical shock when a blue light was illuminated but that no shock would be given when a yellow light was turned on. When the blue light appeared, the amygdala and other regions of the brain responsible for fear reactions became active, although no shock was actually administered. When the yellow light was illuminated, no reactions were recorded. —R.V.

Neurons learn fear by synthesizing proteins even after an alarming experience stops. Scientists have erased fear reactions by blocking this synthesis.

This proves what Claparède suspected: the conscious memory for facts and the emotional memory are two different systems.

Indeed, in 1890 psychologist William James proposed that “an impression may be so exciting emotionally as almost to leave a scar upon the cerebral tissues.” Today scientists are beginning to understand how such neuronal “scars” arise and produce anxiety disorders. Perhaps they will be able to produce therapeutic drugs to prevent these traces from forming.

It may even be possible to erase the sensation of fear. Experts are increasingly convinced that the so-called long-term potentiation of neurons is crucial to emotional memory. In this mechanism, connections among neurons that are frequently used become etched or hardwired, in part by the cre-

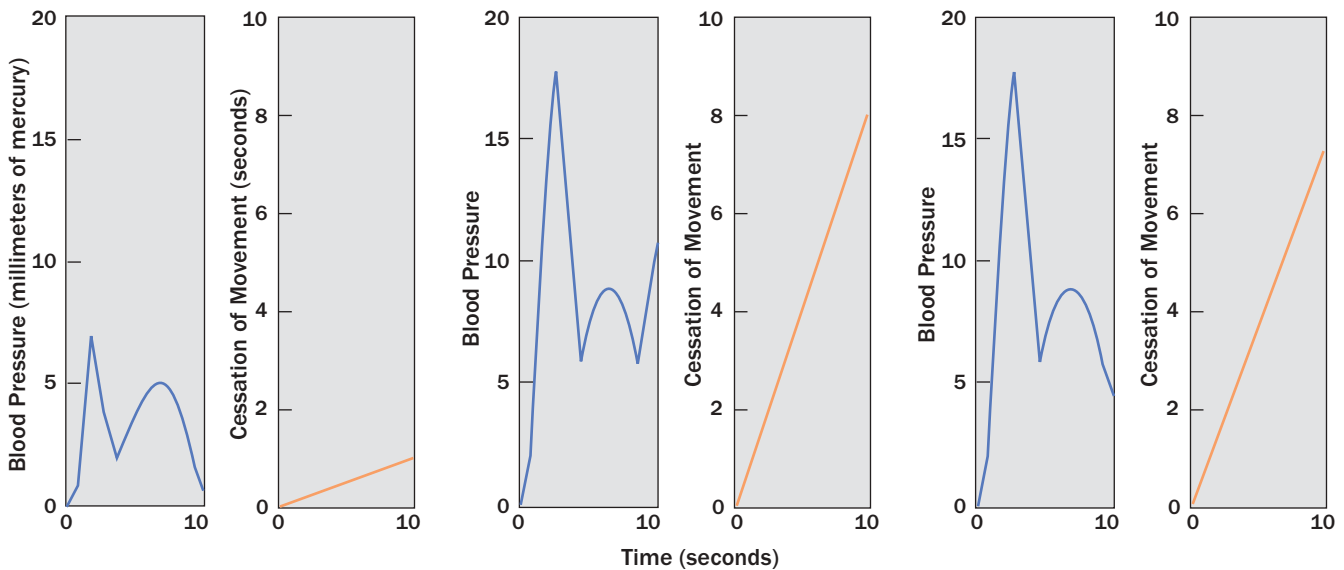
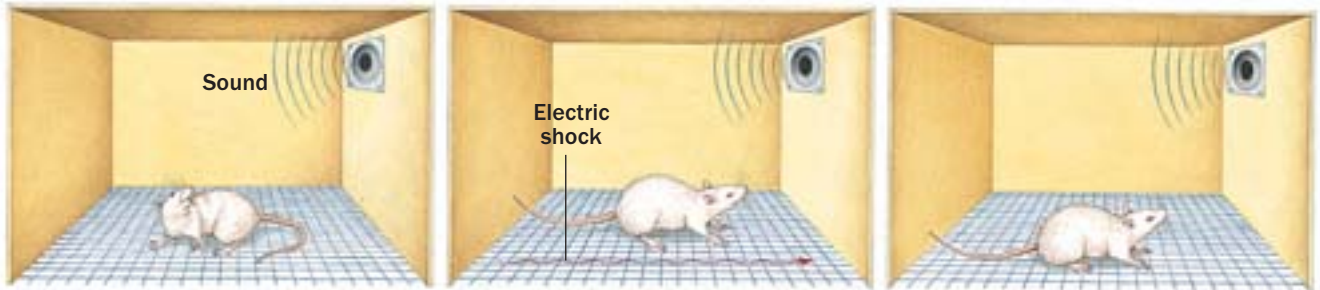
weeks earlier if they can block the synthesis of the related proteins in a part of the amygdala called the basal nucleus. There also appears to be a window of opportunity for interfering with remembered fears soon after the fear memory is reactivated. It might therefore be possible to erase traumatic memories with drugs.

Erasing debilitating fears remains a hope for the future. Right now researchers are simply trying to “turn off” conditioned responses to stimuli.

(The Author)

RÜDIGER VAAS is a neurobiologist, philosopher and writer. He has written numerous articles and books about brain research and once feared for his life when he nearly stepped on a rattlesnake in the Sonoran Desert.

There are far fewer connections from the cortex to the amygdala than vice versa, giving rational thought little power to control the emotions of fear.



When a rat is given an auditory stimulus (left), its blood pressure rises only slightly and the animal barely tenses its body. But when the tone is coupled with a weak electric shock through the floor (center), the rat clearly stiffens its body and its blood pressure jumps. After several repetitions, its physiological reaction is the same even when it only hears the tone (right), having conditioned itself to the fear that the tone implies.

Classic psychology experiments have shown that when rats are first conditioned with an electrical shock to fear a tone when it sounds, they later fear the tone even without the associated shock. Yet after they repeatedly hear the tone for some time without the shock, the learned fear reaction disappears. Researchers have determined that the reaction is not forgotten but is being actively suppressed by the nervous system, under the direction of the cerebral cortex.

What actually happens during suppression? When a fear reaction is conditioned, the neurons

involved group themselves into ensembles that act in unison. These ensembles remain after suppression but do not react because they no longer propagate an activating impulse. This means that even after the reaction is curbed, the ensembles can become reactivated by a new impulse—which is probably how phobias arise.

Drugs or Dialogue?

Finding chemical compounds that could suppress remembered fears will be a challenge. In the meantime, researchers are trying to improve

drugs that can interfere with the chemical messengers that have been shown to arouse anxiety: the neurotransmitters.

The success of certain psychotropic drugs indicates that anxiety disorders can arise from the presence of too little GABA—gamma-aminobutyric acid, an inhibitory neurotransmitter. The benzodiazepine tranquilizers such as chlordiazepoxide (Librium) or diazepam (Valium) bind to GABA receptors and reinforce the effects of the transmitter. Animal experiments show that targeted delivery of benzodiazepines to the amygdala—which is rich in GABA receptors—lessens anxiety, whereas GABA antagonists block this effect. In addition, researchers have found a small protein in the brains of both humans and rats that can bring about anxiety, apparently by docking to the benzodiazepine binding sites of the GABA receptors.

Along with GABA, the neurotransmitter serotonin also influences anxiousness. Drugs such as fluoxetine (Prozac) affect the serotonin receptors. And irregularities in the dopamine system can also lead to some types of anxiety disorders.

Psychotherapy is the alternative to drugs for curing anxiety disorders. Doctors have developed

(Dread or Fear?)

Specialists and laypeople often differentiate between dread and fear. Dread is a general, objectless, diffuse feeling that does not necessarily lead to a certain action. It causes a person to become more aware of his or her environment, the senses are heightened and the perception of pain increases. Fear, however, focuses on a specific object or situation-oriented feeling and results in concrete actions such as hiding or confrontation as well as a reduction in the perception of pain. Dread comes more from within, whereas fear stems more from the outside world. —R.V.

and anxieties. There are far fewer connections from the cortex to the amygdala than vice versa—perhaps giving rational thought little sway. The imbalance is why fears and other emotions can so easily overwhelm us and why it is so hard to voluntarily suppress such feelings. This must be the reason that therapy often goes on so long and often is only somewhat effective.

Psychotherapists and drug designers face a difficult task: the human mind excels at creating fears and preserving them. We have more fears than we need.

various therapies, and great controversy exists over which are effective. Psychoanalysts, for example, seek to resolve a patient's unconscious conflicts, from which they claim anxieties spring. Cognitive talk therapists try to get anxieties under control by helping a patient change his or her attitude toward certain stimuli.

Behaviorists, for their part, doubt the significance of unconscious memories and attempt to treat symptoms, which seems to be helpful with phobias. Some behaviorists try to gradually reduce a patient's sensitivity to an anxiety-provoking stimulus by slowly getting him or her accustomed to it. Others use "exposure therapy"—bringing the patient face-to-face with the stimulus in a massive, shocking way in order to "deaden" him or her to it. Both therapies aim to induce "counterconditioning," which supposedly causes the patient to "unlearn" the anxiety.

Regardless of their methods, therapists and drug designers face a difficult task in calming fears

We humans also excel at creating fears. One of the most powerful and effective functions of the brain, says New York University neurobiologist Joseph E. LeDoux, is the ability to quickly fashion memories out of stimuli that are connected to hazards, then preserve them for a long time and automatically put them to use when similar situations arise in the future. Yet, he notes, this incredible luxury is expensive—we have more fears than we need. The fault, LeDoux maintains, seems to lie with our extraordinarily effective fear-conditioning system, activated by our well-developed ability to imagine fears and our inability to control them.

(Further Reading)

- ◆ **Handbook of Anxiety.** Five volumes. Edited by Martin Roth et al. Elsevier, 1988–1993.
- ◆ **The Emotional Brain.** Joseph E. LeDoux. Simon & Schuster, 1996.
- ◆ **Neuropsychology of Fear and Loathing.** Andrew J. Calder et al. in *Nature Reviews Neuroscience*, Vol. 2, pages 352–363; May 2001.

By Robert B. Cialdini

the SCIENCE of Persuasion

Social psychology has determined
the basic principles that govern
getting to “yes”

Hello there.

I hope you've enjoyed the magazine so far. Now I'd like to let you in on something of great importance to you personally. Have you ever been tricked into saying yes? Ever felt trapped into buying something you didn't really want or contributing to some suspicious-sounding cause? And have you ever wished you understood why you acted in this way so that you could withstand these clever ploys in the future?

Yes? Then clearly this article is just right for you. It contains valuable information on the most powerful psychological pressures that get you to say yes to requests. And it's chock-full of NEW, IMPROVED research showing exactly how and why these techniques work. So don't delay, just settle in and get the information that, after all, you've already agreed you want.

The scientific study of the process of social influence has been under way for well over half a century, beginning in earnest with the propaganda, public information and persuasion programs of World War II. Since that time, numerous social scientists have investigated the ways in which one individual can influence another's attitudes and actions. For the past 30 years, I have participated in that endeavor, concentrating primarily on the major factors that bring about a specific form of behavior change—compliance with a request. Six basic tendencies of human behavior come into play in generating a positive response: recip-

rocation, consistency, social validation, liking, authority and scarcity. As these six tendencies help to govern our business dealings, our societal involvements and our personal relationships, knowledge of the rules of persuasion can truly be thought of as empowerment.

Reciprocation

When the Disabled American Veterans organization mails out requests for contributions, the appeal succeeds only about 18 percent of the time. But when the mailing includes a set of free personalized address labels, the success rate almost doubles, to 35 percent. To understand the effect of



STEVEN ADAMS AP Photo/Tribune-Review

the unsolicited gift, we must recognize the reach and power of an essential rule of human conduct: the code of reciprocity.

All societies subscribe to a norm that obligates individuals to repay in kind what they have received. Evolutionary selection pressure has probably entrenched the behavior in social animals such as ourselves. The demands of reciprocity begin to explain the boost in donations to the veterans group. Receiving a gift—unsolicited and perhaps even unwanted—convinced significant numbers of potential donors to return the favor.

Charitable organizations are far from alone in taking this approach: food stores offer free samples, exterminators offer free in-home inspections,

health clubs offer free workouts. Customers are thus exposed to the product or service, but they are also indebted. Consumers are not the only ones who fall under the sway of reciprocity. Pharmaceutical companies spend millions of dollars every year to support medical researchers and to provide gifts to individual physicians—activities that may subtly influence investigators' findings and physicians' recommendations. A 1998 study in the *New England Journal of Medicine* found that only 37 percent of researchers who published conclusions critical of the safety of calcium channel blockers had previously received drug company support. Among those whose conclusions attested to the drugs' safety, however, the number of

Free samples carry a subtle price tag; they psychologically indebt the consumer to reciprocate. Here shoppers get complimentary tastes of a new product, green ketchup.

Public commitment of signing a petition influences the signer to behave consistently with that position in the future.



those who had received free trips, research funding or employment skyrocketed—to 100 percent.

Reciprocity includes more than gifts and favors; it also applies to concessions that people make to one another. For example, assume that you reject my large request, and I then make a concession to you by retreating to a smaller request. You may very well then reciprocate with a concession of your own: agreement with my lesser request. In the mid-1970s my colleagues and I conducted an experiment that clearly illustrates the dynamics of reciprocal concessions. We stopped a random sample of passersby on public walkways and asked them if they would volunteer to chaperone juvenile detention center inmates on a day trip to the zoo. As expected, very few complied, only 17 percent.

For another random sample of passersby, however, we began with an even larger request: to serve as an unpaid counselor at the center for two hours per week for the next two years. Everyone in this second sampling rejected the extreme appeal. At that point we offered them a concession. “If you can’t do that,” we asked, “would you chaperone a group of juvenile detention center inmates on a day trip to the zoo?” Our concession powerfully stimulated return concessions. The compliance rate nearly tripled, to 50 percent, compared with the straightforward zoo-trip request.

Consistency

In 1998 Gordon Sinclair, the owner of a well-known Chicago restaurant, was struggling with a problem that afflicts all restaurateurs. Patrons frequently reserve a table but, without notice, fail to appear. Sinclair solved the problem by asking his receptionist to change two words of what she said to callers requesting reservations. The change dropped his no-call, no-show rate from 30 to 10 percent immediately.

The two words were effective because they commissioned the force of another potent human motivation: the desire to be, and to appear, consistent. The receptionist merely modified her request from “Please call if you have to change your plans” to “Will you please call if you have to change your plans?” At that point, she politely paused and waited for a response. The wait was pivotal because it induced customers to fill the pause with a public commitment. And public commitments, even seemingly minor ones, direct future action.

In another example, Joseph Schwarzwald of

LUIS M. ALVAREZ AP Photo

FAST FACTS

Persuasive Techniques

1 >> Six basic tendencies of human behavior come into play in generating a positive response to a request: reciprocity, consistency, social validation, liking, authority and scarcity.

2 >> Knowledge of these tendencies can empower consumers and citizens to make better-informed decisions about, for example, whether to purchase a product or vote for legislation.

3 >> The six key factors are at work in various areas around the world as well, but cultural norms and traditions can modify the weight brought to bear by each factor.

Bar-Ilan University in Israel and his co-workers nearly doubled monetary contributions for the handicapped in certain neighborhoods. The key factor: two weeks before asking for contributions, they got residents to sign a petition supporting the handicapped, thus making a public commitment to that same cause.

Social Validation

On a wintry morning in the late 1960s, a man stopped on a busy New York City sidewalk and gazed skyward for 60 seconds, at nothing in particular. He did so as part of an experiment by City University of New York social psychologists Stanley Milgram, Leonard Bickman and Lawrence Berkowitz that was designed to find out what effect this action would have on passersby. Most simply detoured or brushed by; 4 percent joined the man in looking up. The experiment was then repeated with a slight change. With the modification, large numbers of pedestrians were induced to come to a halt, crowd together and peer upward.

The single alteration in the experiment incorporated the phenomenon of social validation. One fundamental way that we decide what to do in a situation is to look to what others are doing or have done there. If many individuals have decided in favor of a particular idea, we are more likely to follow, because we perceive the idea to be more correct, more valid.

Milgram, Bickman and Berkowitz introduced the influence of social validation into their street experiment simply by having five men rather than one look up at nothing. With the larger initial set of upward gazers, the percentage of New Yorkers who followed suit more than quadrupled, to 18 percent. Bigger initial sets of planted up-lookers generated an even greater response: a starter group of 15 led 40 percent of passersby to join in, nearly stopping traffic within one minute.

Taking advantage of social validation, requesters can stimulate our compliance by demonstrating (or merely implying) that others just like us have already complied. For example, a study found that a fund-raiser who showed homeowners a list of neighbors who had donated to a local charity significantly increased the frequency of contributions; the longer the list, the greater the effect. Marketers, therefore, go out of their way to inform us when their product is the largest-selling or fastest-growing of its kind, and television commercials regularly depict crowds rushing to stores to acquire the advertised item.

Less obvious, however, are the circumstances under which social validation can backfire to pro-

duce the opposite of what a requester intends. An example is the understandable but potentially misguided tendency of health educators to call attention to a problem by depicting it as regrettably frequent. Information campaigns stress that alcohol and drug use is intolerably high, that adolescent suicide rates are alarming and that polluters are spoiling the environment. Although the claims are both true and well intentioned, the creators of these campaigns have missed something basic about the compliance process. Within the statement “Look at all the people who are doing this *undesirable* thing” lurks the powerful and undercutting message “Look at all the people who *are* doing this undesirable thing.” Research shows that, as a consequence, many such programs boomerang, generating even more of the undesirable behavior.

For instance, a suicide intervention program administered to New Jersey teenagers informed them of the high number of teenage suicides. Health researcher David Shaffer and his colleagues at Columbia University found that participants became significantly more likely to see suicide as a potential solution to their problems. Of greater effectiveness are campaigns that honestly depict the unwanted activity as damaging despite the fact that relatively few individuals engage in it.

Liking

“Affinity,” “rapport” and “affection” all describe a feeling of connection between people. But the simple word “liking” most faithfully captures the concept and has become the standard designation in the social science literature. People prefer to say yes to those they like. Consider the worldwide success of the Tupperware Corporation and its “home party” program. Through the in-home demonstration get-together, the company arranges for its customers to buy from a liked friend, the host, rather than from an unknown salesperson. So favorable has been the effect on proceeds that, according to company literature, a Tupperware party begins somewhere in the world every two seconds. In fact, 75 percent of all Tupperware parties today occur outside the individualistic U.S., in countries where group social bonding is even more important than it is here.

Of course, most commercial transactions take place beyond the homes of friends. Under these much more typical circumstances, those who wish to commission the power of liking employ tactics clustered around certain factors that research has shown to work.

Physical attractiveness can be such a tool. In a



Social validation takes advantage of peer pressure to drive human behavior. Poorly applied, however, it can also undermine attempts to curtail deleterious activities, by pointing out their ubiquity: If everyone's doing it, why shouldn't I?

1993 study conducted by Peter H. Reingen of Arizona State University and Jerome B. Kernan, now at George Mason University, good-looking fundraisers for the American Heart Association generated nearly twice as many donations (42 versus 23 percent) as did other requesters. In the 1970s researchers Michael G. Efran and E.W.J. Patterson of the University of Toronto found that voters in Canadian federal elections gave physically at-

quests, the amount of the donations more than doubled.

Compliments also stimulate liking, and direct salespeople are trained in the use of praise. Indeed, even inaccurate praise may be effective. Research at the University of North Carolina at Chapel Hill found that compliments produced just as much liking for the flatterer when they were untrue as when they were genuine.

(Are we then doomed to be helplessly manipulated by these principles? No.)

Behold the power of authority. Certainly not lost on the National Rifle Association is that the authority inherent in such heroic figures as Moses, El Cid and Ben-Hur is linked to the actor who portrayed them, Charlton Heston.

tractive candidates several times as many votes as unattractive ones. Yet such voters insisted that their choices would never be influenced by something as superficial as appearance.

Similarity also can expedite the development of rapport. Salespeople often search for, or outright fabricate, a connection between themselves and their customers: “Well, no kidding, you’re from Minneapolis? I went to school in Minnesota!” Fund-raisers do the same, with good results. In 1994 psychologists R. Kelly Aune of the University of Hawaii at Manoa and Michael D. Basil of the University of Denver reported research in which solicitors canvassed a college campus asking for contributions to a charity. When the phrase “I’m a student, too” was added to the re-

Cooperation is another factor that has been shown to enhance positive feelings and behavior. Salespeople, for example, often strive to be perceived by their prospects as cooperating partners. Automobile sales managers frequently cast themselves as “villains” so the salesperson can “do battle” on the customer’s behalf. The gambit naturally leads to a desirable form of liking by the customer for the salesperson, which promotes sales.

Authority

Recall the man who used social validation to get large numbers of passersby to stop and stare at the sky. He might achieve the opposite effect and spur stationary strangers into motion by assuming the mantle of authority. In 1955 University of Texas at Austin researchers Monroe Lefkowitz, Robert R. Blake and Jane S. Mouton discovered that a man could increase by 350 percent the number of pedestrians who would follow him across the street against the light by changing one simple thing. Instead of casual dress, he donned markers of authority: a suit and tie.

Those touting their experience, expertise or scientific credentials may be trying to harness the power of authority: “Babies are our business, our only business,” “Four out of five doctors recommend,” and so on. (The author’s biography on the opposite page in part serves such a purpose.) There is nothing wrong with such claims when they are real, because we usually want the opinions of true authorities. Their insights help us choose quickly and well.

The problem comes when we are subjected to phony claims. If we fail to think, as is often the case when confronted by authority symbols, we can easily be steered in the wrong direction by ersatz experts—those who merely present the aura of legitimacy. That Texas jaywalker in a suit and tie was no more an authority on crossing the street



RIC FELD AP Photo



than the rest of the pedestrians who nonetheless followed him. A highly successful ad campaign in the 1970s featured actor Robert Young proclaiming the health benefits of decaffeinated coffee. Young seems to have been able to dispense this medical opinion effectively because he represented, at the time, the nation's most famous physician. That Marcus Welby, M.D., was only a character on a TV show was less important than the appearance of authority.

Scarcity

While at Florida State University in the 1970s, psychologist Stephen West noted an odd occurrence after surveying students about the campus cafeteria cuisine: ratings of the food rose significantly from the week before, even though there had been no change in the menu, food quality or preparation. Instead the shift resulted from an announcement that because of a fire, cafeteria meals would not be available for several weeks.

This account highlights the effect of perceived scarcity on human judgment. A great deal of evidence shows that items and opportunities become more desirable to us as they become less available.

For this reason, marketers trumpet the unique benefits or the one-of-a-kind character of their offerings. It is also for this reason that they consistently engage in "limited time only" promotions or put us into competition with one another using sales campaigns based on "limited supply."

Less widely recognized is that scarcity affects the value not only of commodities but of information as well. Information that is exclusive is more persuasive. Take as evidence the dissertation data of a former student of mine, Amram Knishinsky, who owned a company that imported beef into the U.S. and sold it to supermarkets. To examine the effects of scarcity and exclusivity on compliance, he instructed his telephone sales-

Friends (who are already liked) are powerful sales-people, as Tupperware Corporation discovered. Strangers can co-opt the trappings of friendship to encourage compliance.

(The Author)

ROBERT B. CIALDINI is Regents' Professor of Psychology at Arizona State University, where he has also been named Distinguished Graduate Research Professor. He is past president of the Society of Personality and Social Psychology. Cialdini's book *Influence*, which was the result of a three-year study of the reasons why people comply with requests in everyday settings, has appeared in numerous editions and been published in nine languages. He attributes his longstanding interest in the intricacies of influence to the fact that he was raised in an entirely Italian family, in a predominantly Polish neighborhood, in a historically German city (Milwaukee), in an otherwise rural state.

people to call a randomly selected sample of customers and to make a standard request of them to purchase beef. He also instructed the salespeople to do the same with a second random sample of customers but to add that a shortage of Australian beef was anticipated, which was true, because of certain weather conditions there. The added information that Australian beef was soon to be scarce more than doubled purchases.

Finally, he had his staff call a third sample of customers, to tell them (1) about the impending shortage of Australian beef and (2) that this information came from his company's *exclusive*

sources in the Australian national weather service. These customers increased their orders by more than 600 percent. They were influenced by a scarcity double whammy: not only was the beef scarce, but the information that the beef was scarce was itself scarce.

Knowledge Is Power

I think it noteworthy that many of the data presented in this article have come from studies of the practices of persuasion professionals—the marketers, advertisers, salespeople, fund-raisers and their comrades whose financial well-being de-

(Influence across Cultures)

Do the six key factors in the social influence process operate similarly across national boundaries? Yes, but with a wrinkle. The citizens of the world are human, after all, and susceptible to the fundamental tendencies that characterize all members of our species. Cultural norms, traditions and experiences can, however, modify the weight that is brought to bear by each factor.

Consider the results of a report published in 2000 by Stanford University's Michael W. Morris, Joel M. Podolny and Sheira Ariel, who studied employees of Citibank, a multinational financial corporation. The researchers selected four societies for examination: the U.S., China, Spain and Germany. They surveyed Citibank branches within each country and measured employees' willingness to comply voluntarily with a request from a co-worker for assistance with a task. Although multiple key factors could come into play, the main reason employees felt obligated to comply differed in the four nations. Each of these reasons incorporated a different fundamental principle of social influence.

Employees in the U.S. took a reciprocation-based approach to the decision to comply. They asked the question, "What has this person done for me recently?" and felt obligated to volunteer if they owed the requester a favor. Chinese employees responded primarily to authority, in the form of loyalties to those of high status within their small group. They asked, "Is this requester connected to someone in my unit, especially someone who is high-ranking?" If the answer was yes, they felt required to yield.

Spanish Citibank personnel based the deci-



Cultural norms can alter perceptions of persuasion tactics.

sion to comply mostly on liking/friendship. They were willing to help on the basis of friendship norms that encourage faithfulness to one's friends, regardless of position or status. They asked, "Is this requester connected to my friends?" If the answer was yes, they were especially likely to want to comply.

German employees were most compelled by consistency, offering assistance in order to be consistent with the rules of the organization. They decided whether to comply by asking, "According to official regulations and categories, am I supposed to assist this requester?" If the answer was yes, they felt a strong obligation to grant the request.

In sum, although all human societies seem to play by the same set of influence rules, the weights assigned to the various rules can differ across cultures. Persuasive appeals to audiences in distinct cultures need to take such differences into account. —R.B.C.

depends on their ability to get others to say yes. A kind of natural selection operates on these people, as those who use unsuccessful tactics soon go out of business. In contrast, those using procedures that work well will survive, flourish and pass on these successful strategies [see “The Power of Memes,” by Susan Blackmore; *SCIENTIFIC AMERICAN*, October 2000]. Thus, over time, the most effective principles of social influence will appear in the repertoires of long-standing persuasion professions. My own work indicates that those principles embody the six fundamental human tendencies examined in this article: reciprocity, consistency, social validation, liking, authority and scarcity.

From an evolutionary point of view, each of the behaviors presented would appear to have been selected for in animals, such as ourselves, that must find the best ways to survive while living in social groups. And in the vast majority of cases, these principles counsel us correctly. It usually makes great sense to repay favors, behave consistently, follow the lead of similar others, favor the requests of those we like, heed legitimate authorities and value scarce resources. Consequently, influence agents who use these principles honestly do us a favor. If an advertising agency, for instance, focused an ad campaign on the genuine weight of authoritative, scientific evidence favoring its client’s headache product, all the right people would profit—the agency, the manufacturer and the audience. Not so, however, if the agency, finding no particular scientific merit in the pain reliever, “smuggles” the authority principle into the situation through ads featuring actors wearing white lab coats.

Are we then doomed to be helplessly manipulated by these principles? No. By understanding persuasion techniques, we can begin to recognize strategies and thus truly analyze requests and offerings. Our task must be to hold persuasion professionals accountable for the use of the six powerful motivators and to purchase their products and services, support their political proposals or donate to their causes only when they have acted truthfully in the process.

If we make this vital distinction in our dealings with practitioners of the persuasive arts, we will rarely allow ourselves be tricked into assent. Instead we will give ourselves a much better option: to be informed into saying yes. Moreover, as long as we apply the same distinction to our own attempts to influence others, we can legitimately commission the six principles. In seeking to persuade by pointing to the presence of genuine ex-



pertise, growing social validation, pertinent commitments or real opportunities for cooperation, and so on, we serve the interests of both parties and enhance the quality of the social fabric in the bargain.

Surely, someone with your splendid intellect can see the unique benefits of this article. And because you look like a helpful person who would want to share such useful information, let me make a request. Would you buy this issue of the magazine for 10 of your friends? Well, if you can’t do that, would you show it to just one friend? Wait, don’t answer yet. Because I genuinely like you, I’m going to throw in—at absolutely no extra cost—a set of references that you can consult to learn more about this little-known topic.

Now, will you voice your commitment to help?... Please recognize that I am pausing politely here. But while I’m waiting, I want you to feel totally assured that many others just like you will certainly consent. And I love that shirt you’re wearing.

Limited offer of toys available for a short time often creates a figurative feeding frenzy at local fast-food establishments. Scarcity can be manufactured to make a commodity appear more desirable.

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- ◆ For regularly updated information about the social influence process, visit www.influenceatwork.com



By Raphaël Hitier,
Florian Petit and Thomas Prémat

memories of a **FLY**

Tiny and ubiquitous,
the fruit fly is a helpful
model for the study
of memory

SUZANNE BARNES (left); DAVID M. PHILLIPS Photo Researchers, Inc. (right)

Fruit flies have had a larger-than-life impact on the study of memory, as this magnified and colored image, made with a raster electron microscope, suggests.



We watch the tiny fruit fly as it wriggles around in a wineglass—not exactly the brainy type. Yet *Drosophila melanogaster*, as it is

known by its proper scientific name, has an impressive capacity for learning. We can train it, much like Pavlov’s famous dogs, to react to certain stimuli. And when it comes to some tasks, such as choosing a mate, the fly has the memory of an elephant, so to speak; once it learns the scent of an unreceptive, mated female, it essentially “never forgets.”

But this trait isn’t the only reason scientists look to fruit flies for clues about how memories form in humans. *Drosophila*, along with such animals as the mouse and sea slug, offers convenience for research. Just slightly larger than an asterisk, the fruit fly is easy to breed and keep. It has a relatively uncomplicated genome with only four chromosome pairs; sequences of the insect’s inherited genetic material were completely mapped in 2000.

From these DNA sequences, scientists have confirmed that although the nervous systems of fruit flies and humans differ anatomically, the responsible genes, and therefore the proteins coded by them, are rather similar. (Proteins direct chemical processes in cells.) Most of the genes isolated in *Drosophila* have corresponding equivalents in mammals. Fruit flies and humans thus share the same fundamental characteristics for storing information, inherited from our earliest known ancestors. In recent years, studies of these molecular mechanisms in flies have yielded new insights about memory.

Lords of the Flies

To study fly memory, scientists start with a line of laboratory flies, called Canton-S, that possess strong recall. From this line, they breed additional stock, which differs from its parents by a single artificially produced mutation, or change, in the inheritable information. If the change affects a gene that carries information for memory capacity, the mutant could possess a relatively inferior memory. By studying the deficiency symptoms, researchers can discover which functions the protein, and therefore the corresponding gene, fulfill.

But how does one come by thousands of mutated flies so that at least a few possess a defective memory gene? One method, pioneered in the late 1960s by Seymour Benzer of the California Institute of Technology, is to expose fly egg or sperm cells to a chemical mutagen, or mutation-causing agent. Specific substances cause random errors in the DNA sequence; the progeny then inherit those mutations. After identifying a number of mutants with deviations in courtship, vision and circadian rhythms, Benzer and others turned to learning and memory storage. But even when some of the offspring displayed the desired deficient memory, the hardest work still needed to be done: finding out which of the thousands of genes had been affected.

Today scientists prefer to use a transposon as the mutagen. Transposons are naturally occurring gene sequences that can move within the inherited information. If such a “jumping gene” is injected into a fly’s egg cell, it integrates into the inherited material at an arbitrary point and causes a mutation there. The advantage for investigators is that a transposon can be located quickly on the fly’s relatively large chromosomes. The changed gene must reside in the direct vicinity of this element [see box on page 84].

Next, workers sort the desirable subjects from the multitude of mutated fly lines. Each offspring that displays a better or worse memory than typical flies falls in the category of potential memory mutant. On average, researchers find only one or two among hundreds of lines with which they can continue to work.

Additional tests determine conclusively that the mutation causes an altered memory rather than damaging other fundamental abilities, which would give only the impression of impaired memory. In the most commonly used method, flies learn to associate a certain scent with an electric shock [see box on opposite page]; they must be able to sense clearly both the scent and the shocks. Flies may also learn to avoid an unpleasant heat stimulus in a flight simulator.

FAST FACTS

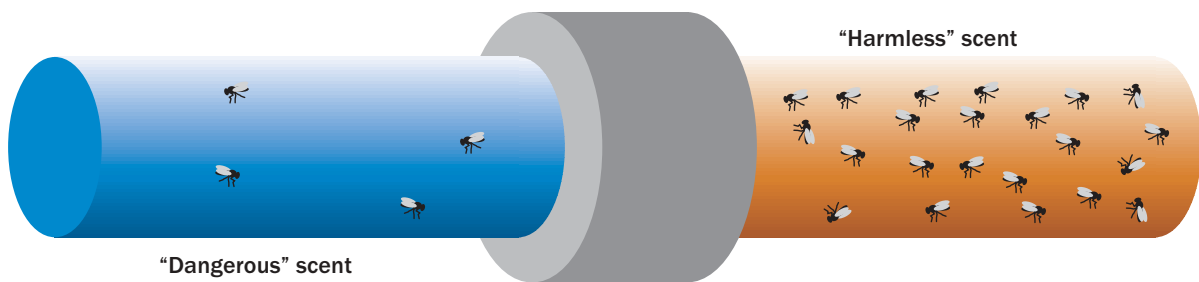
Flies and Memory

- 1** >> The brains of fruit flies and humans have a surprising amount in common—at least at the molecular level. Many of the cellular mechanisms that fruit flies use to form memories are shared by humans.
- 2** >> For the past couple decades, scientists have studied the behavior of mutant fruit flies in which a single gene is affected. Changes in the mutant flies’ behavior provide clues about which genes are responsible.
- 3** >> In addition to revealing more about how the brain works, such genes could also be a target for therapies to treat memory deficiency or other neurological diseases.

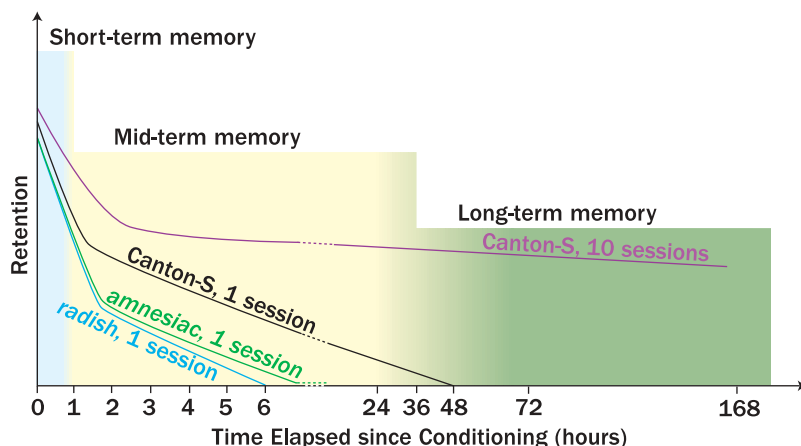
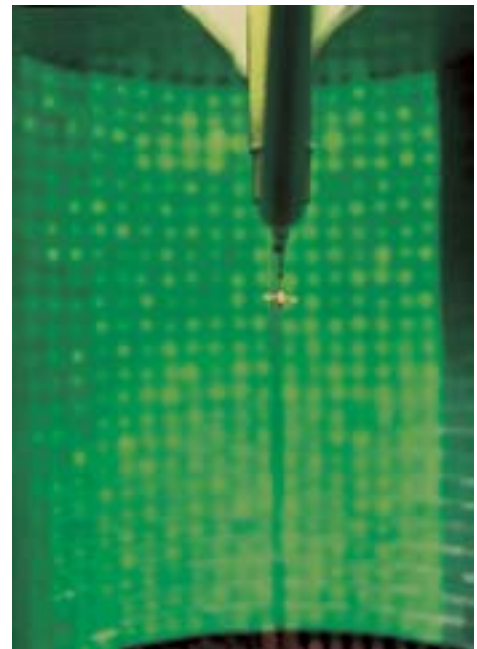
Two Ways to Train Fruit Flies

Their brains are smaller than the head of a pin, but fruit flies can learn. How do scientists train them? In the 1970s Seymour Benzer and his colleagues at the California Institute of Technology began conditioning fruit flies by coupling a specific scent with an electric shock. In an experiment today, a pipe outfitted with metal mesh holds several flies. Blasts of scented air travel through the pipe. The first scent is accompanied by an electric shock delivered

through the mesh; the second is not. The conditioned insects are then put in a central chamber between two compartments (*below*). One section contains the “dangerous” scent; the other has the “harmless” one. Just after the learning phase, more than 80 percent of normal flies make the correct choice by flying toward the harmless scent. The number of mutant flies that prefer the harmless scent becomes the standard for measuring that group’s memory retention.



Another way to train flies is in a flight simulator (*right*), the brainchild of Martin Heisenberg and his team at the University of Würzburg in Germany. Suspended by a piece of copper wire attached to its back, the fly hangs in the center of a movable arena. When the insect wants to turn, the apparatus registers the minuscule fly force. A microprocessor translates the fly’s torque into a corresponding rotation of the arena. If the insect attempts to turn left, the arena rotates to the right to give the fly the impression that it has actually turned. During training, it can choose to “fly” toward either of two areas on the arena wall. One has a *T*, the other, an upside-down *T*. If the fly tries to turn toward the *T*, it receives an uncomfortably warm light and quickly learns to avoid that area. After conditioning, the memory test begins. Scientists record which direction the fly selects without further heat stimulus. From such experiments, we know the fruit fly can retain the stored information of “*T* equals danger” up to 72 hours.



Normal Canton-S fruit flies avoid a “dangerous” scent 24 hours after a single conditioning session. After 10 sessions, the learned information passes into the long-term memory. The mutated lines *amnesiac* and *radish* have worse memories.

It is furthermore important to ascertain that the insect's brain has developed normally—particularly in the so-called mushroom bodies, a cluster of some 5,000 neurons that forms the center for olfactory learning and memory in an insect brain [see box on page 85]. A refined, though time-consuming, method to do so is to restore the normal function of the gene that had been “turned off” in the progeny. If this action repairs the observed change in memory, one can then assume that the brain has developed normally.

Lessons from the Mutants

Over the past couple decades, scientists have developed many such memory mutants. The names often evoke the nature of the variation. For example, Benzer's group identified the first as *dunce*, in 1976. Long after normal flies have absorbed the painful lesson, *dunce* cannot learn how to avoid the electric shock.

Memory has three components: acquisition,

the *rutabaga* line the manufacture of the enzyme adenylyl cyclase is impaired. Both proteins regulate the concentration of cyclic adenosine monophosphate (cAMP), an important messenger molecule in the so-called learning pathway in the mushroom bodies of the fly's brain—and in all other studied animal systems as well. Adenylyl cyclase synthesizes the production of cAMP. Phosphodiesterase destroys cAMP. The *dunce* fly accumulates too much cAMP, which interferes with its ability to acquire and store information. Some researchers see adenylyl cyclase acting in neurons as a kind of coincidence detector for temporally correlated events.

Very generally, here is how adenylyl cyclase helps to connect a given scent with a shock in the fly's brain. Incoming scent signals trigger nerve impulses in the mushroom bodies. The level of adenylyl cyclase in those neurons consequently rises, as does the concentration of cAMP. Meanwhile the stimulus from the electric shock also reaches the brain, and it, too, indirectly simulates the genera-

Simple though they are, flies share many of the same core memory processes with other animals.

storage (learning) and retrieval (recall). Memories are stored as changes in the number and strength of connections between neurons, called synapses. A typical brain cell makes thousands of synapses with other neurons. But only some of those are involved in a particular memory or learned skill. Researchers also generally differentiate between short-term (which in flies lasts from minutes to hours) and long-term (from a few hours to several days) memory. The behavior of *dunce* and other mutants has produced evidence for which genes are responsible for parts of the memory creation process.

Genes involved in the acquisition and storage of short-term memory began to come to light in the early 1980s. After a long and arduous search, Ronald L. Davis and his colleagues at Baylor College of Medicine found the genes for *dunce* and another mutant, *rutabaga*, which both have a poor memory for scents. In *dunce*, production of the enzyme phosphodiesterase is damaged, whereas in

tion of adenylyl cyclase and higher cAMP levels. The fly's brain makes the scent-shock connection when the nerve impulses triggered respectively by the two stimuli run through both channels simultaneously, creating a critical concentration of cAMP. This event boosts the electrical excitability of neurons, so that they become more easily activated from then on. During subsequent memory trials, the scent alone suffices to trigger the same signal cascade that had previously caused the fly to flee from a shock accompanied by the scent.

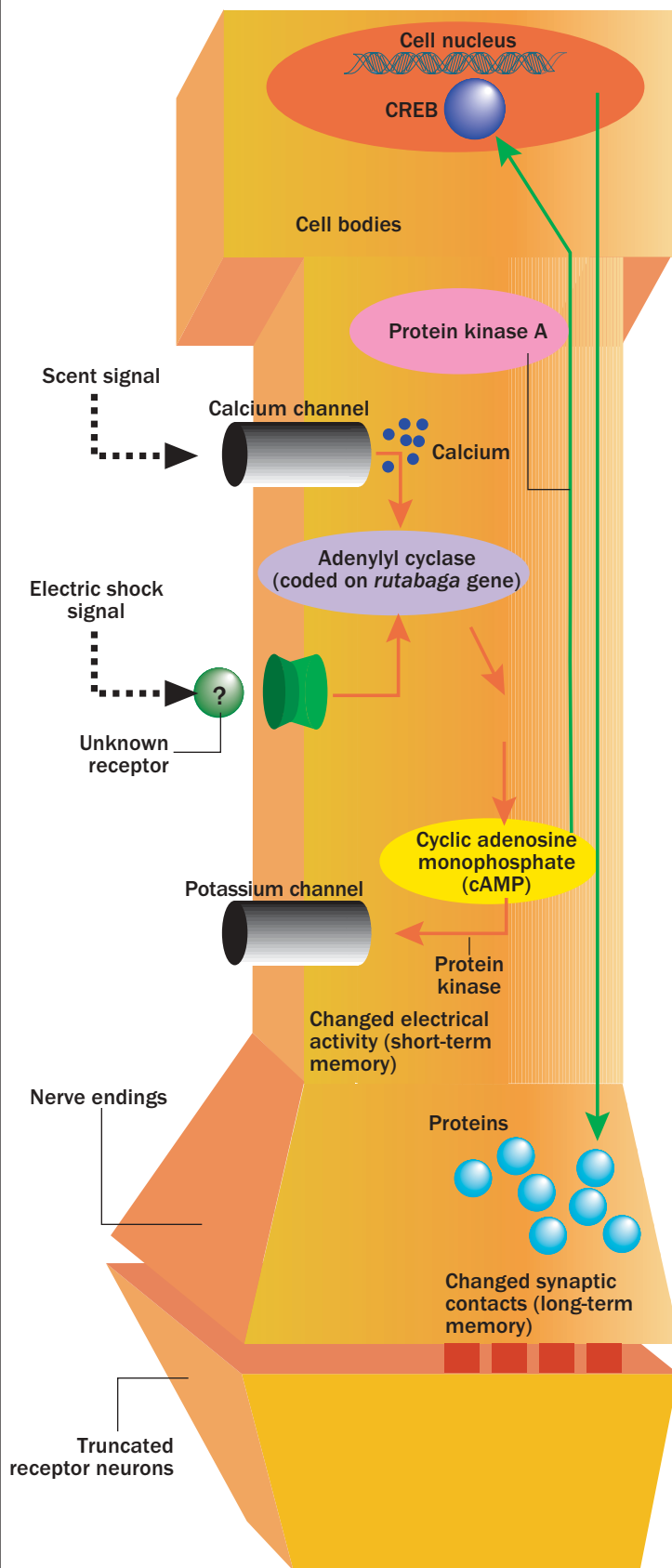
Test results with another mutant, *volado* (Chilean slang for “absentminded”), which Davis and his colleagues reported in 1998, suggest that a protein aids in physically rearranging neurons in the mushroom bodies as they rewire to form a short-term memory. The protein that is suppressed in *volado*, α -integrin, helps cells talk more efficiently to their neighbors. Even just a few minutes after scent-shock training, the forgetful *volado* mutants hopped away from the scent only half as often as normal flies. Integrins had been known to aid in cell adhering and communicating, but this was the first time they were implicated in memory formation.

Fruit flies also have a mid-term memory, which lasts from about an hour to one and a half

(The Authors)

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Molecular Foundation of Memory



When a scent and an electric shock are perceived at the same time, those stimuli cause increased activity of an enzyme called adenylyl cyclase in the nerve cells of the mushroom bodies in the insect brain; these bodies are the center of olfactory learning. Adenylyl cyclase produces the cyclic adenosine monophosphate (cAMP) molecule, increasing its concentration in the nerve cells. cAMP then activates protein kinase A, which modifies potassium channels and thereby changes the nerve cell membranes' electrical characteristics, making them more easily excitable. This excitability is one of the foundations of short-term memory.

At the same time, the activated protein kinase infiltrates the cells' nuclei, activating a protein called cAMP-responsive transcription factor, or CREB, which triggers the transcription of certain genes. The proteins that result from the transcription then lead to the formation of new synaptic contacts—connections between neurons—for the long-term memory.

days. It exists in two forms: one is damaged by cold, and the other is not; normal flies cooled to four degrees Celsius (about 39 degrees Fahrenheit) lose only part of the information stored in mid-term memory.

In 1994 Tim Tully of Cold Spring Harbor Laboratory and others found that the cold-insensitive form of mid-term memory appears to be genetically and functionally independent from long-term memory—and it exists in parallel for several days after spaced training. The *radish* line of flies is not capable of anchoring learned information in the stable, mid-term part of its memory, but its cold-sensitive memory capacity is intact. The *amnesiac* line of flies behaves in exactly the opposite manner. The *amnesiac* gene codes for a neuropeptide, a very short protein. In mammals, such a molecule ultimately increases the cAMP concentration in neurons. In *Drosophila*, it could play a similar role during the learning process. It is possible that the neuropeptide leads neurons to produce adenylyl cyclase, which regulates the nerve cells' excitability threshold. The cold-sensitive, mid-term memory is therefore ultimately based on an increase in the mushroom bodies' electrical activity, which is mediated by the neuropeptide. In contrast, consolidated mid-term memory that is resistant to cold must have a molecular foundation.

Memories That Persist

How do short-term memories become enduring ones? As is the case with mammals, the fruit fly's recollection is reinforced when it is conditioned several consecutive times with a break between each session. If a fly receives an electric shock along with a specific scent 10 times, its memory of the association passes into long-term memory and persists for at least one week. For a fruit fly in its natural habitat, this is practically its entire life span. The *amnesiac* line, with its damaged cold-sensitive mid-term memory, does not possess this long-term memory; however, long-term memory functions perfectly in the *radish* line. From these results we know that only those cold-sensitive processes form a prerequisite for long-term memory.

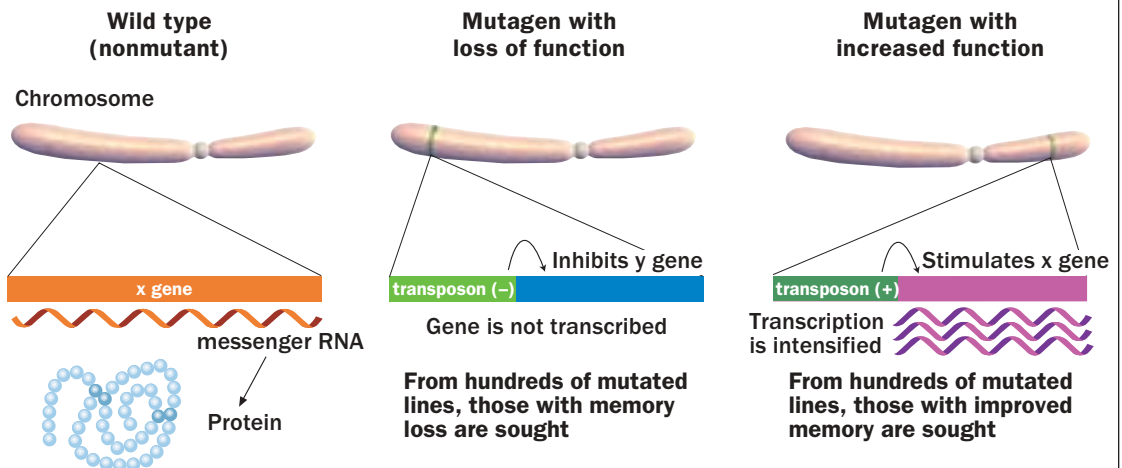
Long-term memory also depends on the synthesis of new proteins, a notion that Tully and his colleagues helped to confirm in 1997. The cAMP molecule is once again part of this process. A high cAMP concentration leads to the activation of the protein kinase A, which in turn activates another protein by the name of CREB, for cAMP-response element binding.

CREB appears to act as a switch for long-term memory formation. It triggers the activation of genes for proteins that direct the formation of new synapses between nerve cells. In normal flies the

Making a Mutant

In normal fruit flies, a gene is transcribed many times and the information is transported to the protein synthesis apparatus as messenger RNA (left). To create mutant flies, scientists insert a transposon, a naturally occurring gene sequence.

If the transposon sits in the gene that blocks the expression of certain proteins (*center*), the fly will show a memory deficiency. Certain transposons allow for an inordinately strong transcription process; such mutants have a better memory (*right*).



Cross Section of a *Drosophila* Head

The centers of scent memory in an insect brain are the mushroom bodies, seen here as L-shaped structures (arrows). The structure, which has symmetrical formations in both halves of the brain, consists of approximately 5,000 total nerve cells, whose axons

form a stem that splits into various lobes. The mushroom bodies receive their information from the antenna lobes, which are responsible for the perception of scents. (The mushroom bodies have been made visible by an antibody bound to a special protein found in the structure.)



switch is turned on after repeated, spaced training sessions. In *dCREB2-a* mutant flies, however, the switch is forced on, producing long-term memory after just one session—the equivalent of a photographic memory for a fly. And in *dCREB2-b* mutants, the switch is off, preventing the creation of long-term memory even after numerous spaced training sessions. *dCREB2* is structurally similar to mammalian CREB genes, so from this research one can glean a rough idea as to how the brain stores information for the long term. The cascade of events that leads to this point, however, is not yet understood in detail—for flies or humans.

In the quest to understand how and where memories are stored, research with flies plays an important part. Relatively simple though they are, flies share many of the same core memory processes with other animals. But fly studies are not sufficient by themselves; mammals are more complex creatures. Work with mice will continue to

help reveal counterparts to the fly memory genes in mammals. As soon as the corresponding mouse genes are discovered, they, too, can be turned off using “knockout” technology, which should teach us a great deal about how those genes function in mammals—including humans. The human versions of the genes would then be potential targets for medicines that might one day slow the progress of degenerative neurological conditions and memory deficit disorders such as Alzheimer’s disease.

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Humbled **BY** HISTORY

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

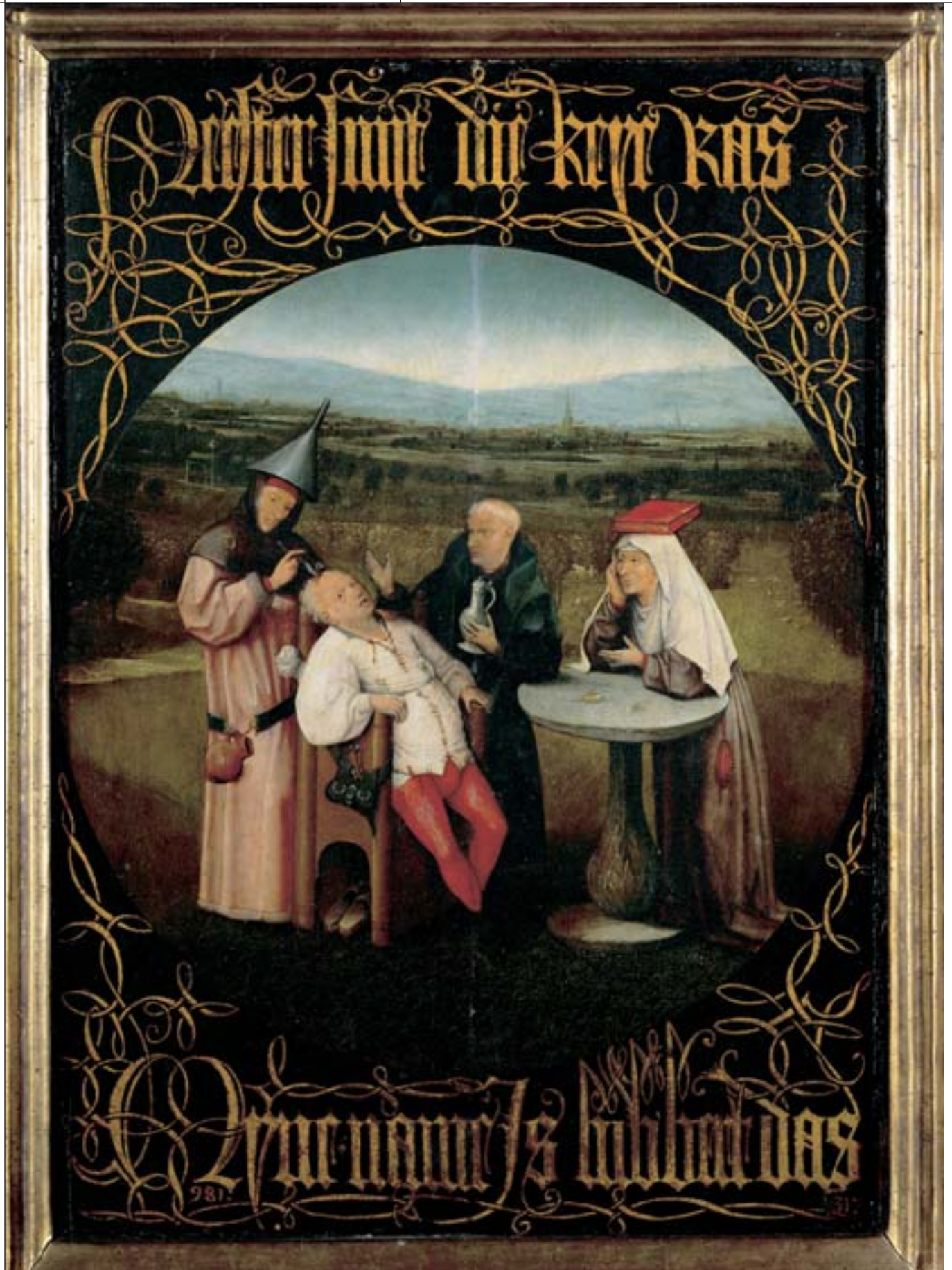
By Robert-Benjamin Illing

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, be-

cause 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.”**



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.



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

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

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

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.

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

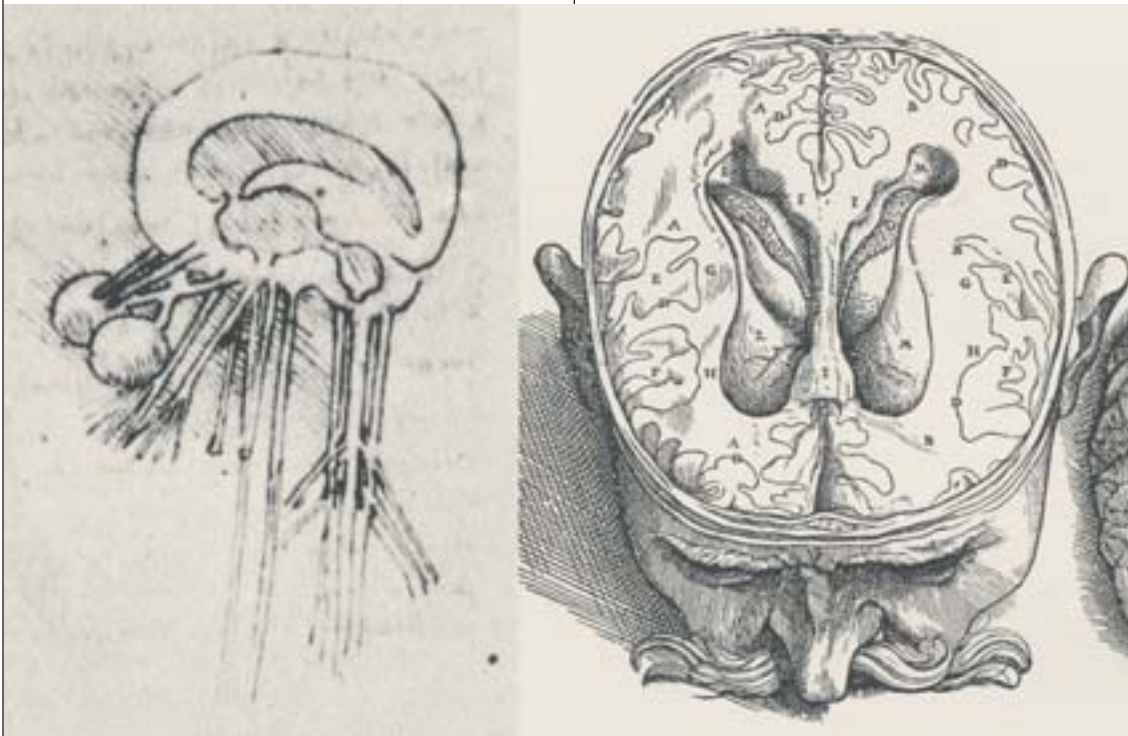
motor events had to be extremely complex. So he devised a new model: a pipe organ. Its air channels corresponded to the heart and arteries, which via the bloodstream carried the *spiritus animalis* to the ventricles. Like organ stops that determined airflow, valves in the nerves helped the *spiritus 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 nervus* (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.

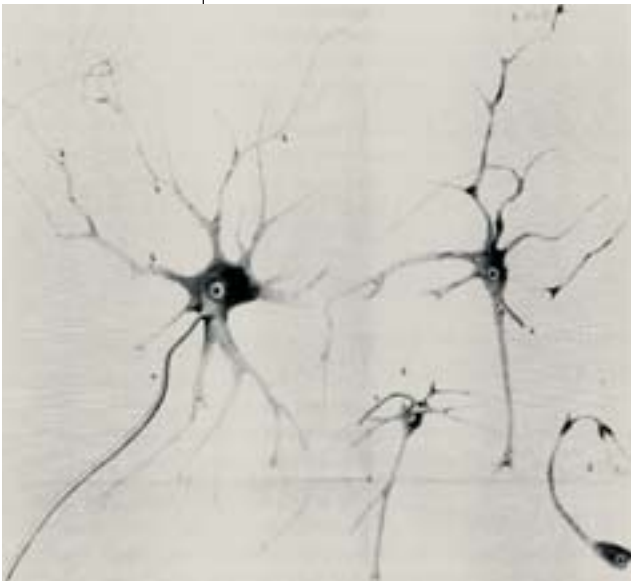
The discussion gained considerable momentum from Italian physician Luigi Galvani (1737–1798). In legendary experiments, he connected a zinc strip to the sciatic nerve of dissected frog legs, then attached the strip with a silver buckle to the muscle. At the moment the circuit was closed and a current 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

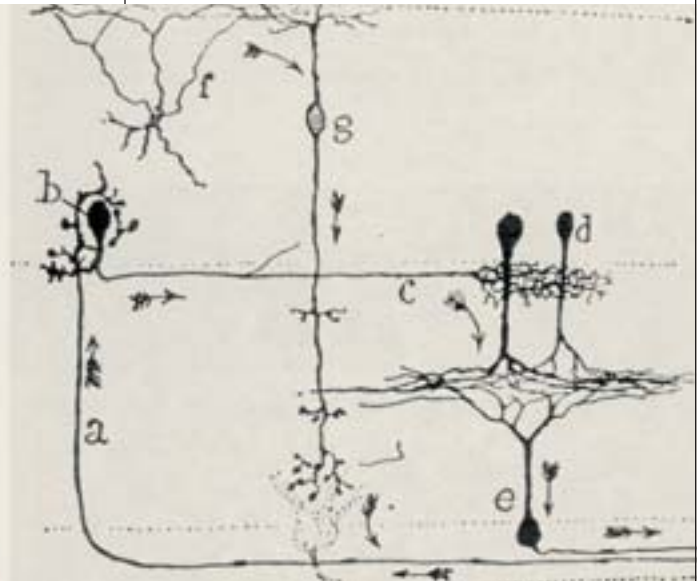
determine that at the end of stained axons there were often special thickenings, so-called terminal buttons. This observation caused him to posit that there was no continuous nerve network, as was believed; instead each neuron was an isolated cell with precisely defined boundaries. In 1906 he shared 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?

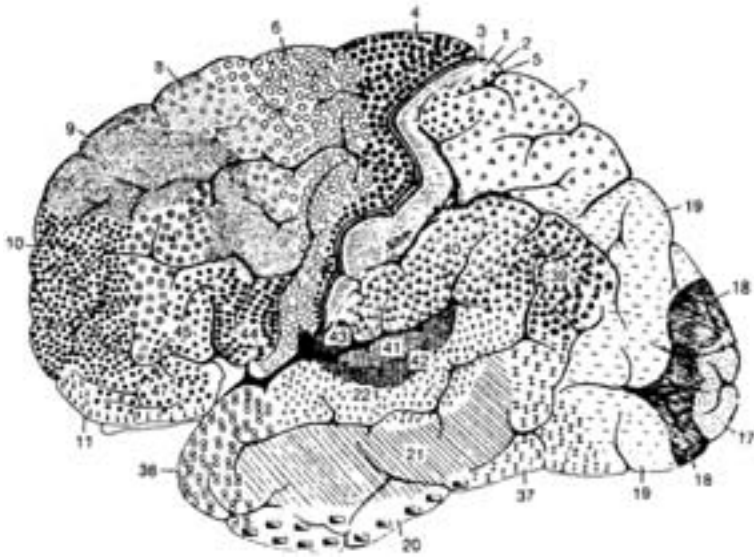
Thomas Willis (1621–1675) had made the first attempts to tie various regions of the brain to specific functions. In his influential work the English doctor declared that the convolutions of the cerebral cortex were the seat of memory and that the white matter within the cerebrum was the seat of the imagination. 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

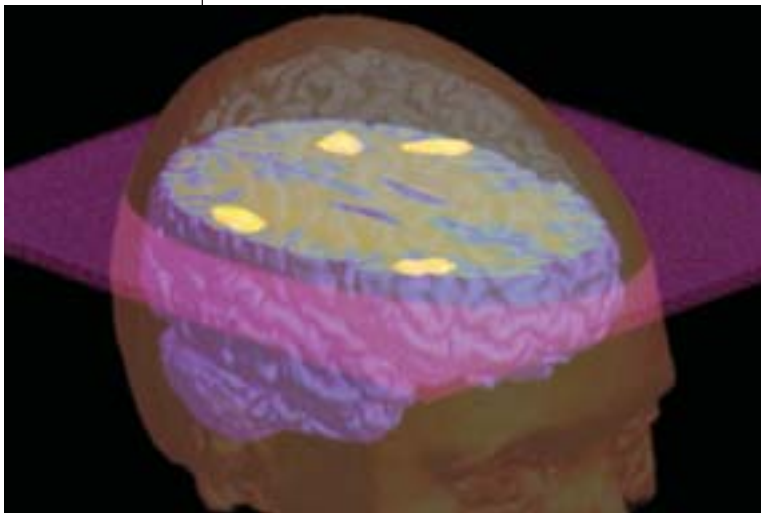
(The Author)

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



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.

one of their muscles or fingers would contract. 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-

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.

bots 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

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

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 ro-

of localized brain function and brain mapping, which had been fading into the background.

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)

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How will we feel when biology can name what makes each of us who we are? BY ROBERT M. SAPOLSKY

Your Personal Pathology

LET'S START with Chuck and Arthur. Chuck works in marketing. Extroverted, charismatic, he's the life of the party in a shallow sort of way; confident and flirtatious, having fidelity problems in his third marriage.

In contrast, Arthur works in accounting. Obsessive, rigidly ethical, he is reliable in his work, to the point that colleagues exploit him; lives alone, spends evenings building model ships.

Revisit them sometime later, however, and both men have undergone

some surprising shifts in personality and behavior. Unexpectedly, Chuck has become withdrawn. He spends more time alone. From out of nowhere, he has developed a passion for painting. He paints in every free moment, producing dark, brooding canvases. In conversation, he effects long silences, which make his customers uncomfortable. That trait will worsen and cost him his job in a few months.

Arthur, meanwhile, has begun telling co-workers dirty jokes. This quirk was

initially entertaining, if puzzling, but the jokes have edged into the lewd and inappropriate. This past weekend at a family get-together, his relatives were unsettled and confused to discover him sucking on the ear of his infant nephew. He has taken to walking the streets in the evening, following attractive women, and is a month away from exposing himself to one of them, which will lead to only the first of many brushes with the law.

Within a few years, both men will be institutionalized.

Some extraordinary things are going on here. First, both men have a neurological rather than a psychiatric disorder. In both, the complex and bizarre behavioral changes are the result of a mutation in a single gene. And, perhaps most remarkably, in both it is the same mutation, producing a condition called frontotemporal dementia.

What are we to make of the fact that the brain can go awry in such puzzling ways? And what are we to make of the fact that we can begin to name, diagnose and comprehend the underpinnings of such dysfunction?

Neuroscience has progressed at a startling speed. We now understand how neurons find and connect to one another during development and how they die after injuries, how our brains decode sensory information and coordinate muscle movement, how sea slugs and even humans learn. Perhaps most excitingly, we are uncovering the brain basis of our behaviors—normal, abnormal and in-between. We are mapping a neurobiology of what makes us *us*.

Remarkable insights are pouring in. There are other single-gene disorders: for example, Huntington's disease, in which the effects on behavior can be as dramatic as those in Chuck and Arthur.

Then there are discoveries that unveil dramatic interactions between genes and the environment. In a recent study, Avshalom Caspi and his colleagues at King's College London reported on a



(We are uncovering the brain basis of our behaviors—**normal, abnormal and in-between.** We are mapping a neurobiology of what makes us *us*.)

JOHN RITTER

form of a gene that increases the risk of major depression. That effect makes sense, in that the gene codes for a protein relevant to serotonin, the neurotransmitter targeted by Prozac and similar antidepressants. But this is not a case of simple genetic determinism, or “genes as destiny.” Instead having that abnormal gene increases the risk of depression only in a stressful environment. Independent work by Klaus-Peter Lesch and his group at the University of Würzburg in Germany shows how glucocorticoids, an important class of stress hormones, regulate expression of this gene.

Some of these findings show the power of the environment in shaping our brains and, thus, who we are. For

otherwise. This discovery suggests that transsexualism is not a problem of thinking that one is the wrong sex. It is a problem of having the body of the wrong sex.

How’s this for odd: there are people with apotemnophilia, who have always thought of themselves as someone who should have an amputated limb. They fantasize about it, conspire to have accidents that will necessitate an amputation, and often actually manage to do it. Psychiatrist Carl Elliott of the University of Minnesota Medical School has termed this “a new way to be mad.”

Obsessive-compulsive disorder, Tourette’s syndrome, borderline personality, avoidant personality, religiosity from

neurobiology. And at least two disturbing things will then happen. First, it will stop being the science of *those* people and *their* diseases and become a descriptor for all of us, as we each get a diagnosis or two from this grab bag of neurobiological abnormalities. That consequence will challenge any thinking person’s conceptions of volition and responsibility.

Second, we eventually will begin to be able to repair these problems—and that bit of progress will also pose dangers. One will be the temptation to fix things that ain’t broke, even to fix them permanently for future generations. Past genocides have been based on external traits of peoples; no doubt we have the capacity to commit genocides based on

(As we all gain a few labels and diagnoses, something is going to become irrelevant: the hard, confident, judgmental wall that differentiates “health” from “disease.”)

example, prolonged trauma can cause atrophy of neurons in a brain region called the hippocampus, which is central to learning and memory, while causing expansion of neurons in the amygdala, a region critical to fear and anxiety.

Other findings, though not as readily categorized in the nature-versus-nurture debate, reveal new ways in which we are the products of our brains. Take a report by Frank Kruijver and his team at the Netherlands Institute of Brain Research. It has been known for some time that in a brain region called the bed nucleus of the striae terminalis (BNST), men and women differ consistently in their number of neurons. Kruijver counted neurons in postmortem human brains, including those from transsexuals. And in both sexes, transsexuals did not have the number of neurons typical of their birth gender. Rather they had the number typical of the sex that they always felt they should be. This pattern was independent of whether the person had actually ever changed sex behaviorally or been treated with hormones.

Think of it: these people’s chromosomes, gonads, genitals, hormones and societal treatment all say they are one gender. But they and their BNSTs insist

temporal lobe epilepsy—for all these conditions and many others, we are seeking (and often finding) explanations in the underlying neuroscience.

This collection may seem like a menagerie of biological oddities. Yet these diagnoses and insights matter. They influence how we educate, whom we educate and whom we tacitly give up on. They influence whom we medicate against their will. And they influence whom we kill. As I work on this essay, I am also preparing for a court appearance in a death penalty hearing. It concerns a man who committed acts so horrific, so nightmarish that just reading his files makes me feel queasy, gives me a panicky need to sneak into my children’s bedrooms to confirm that they are sleeping safely. I will help argue that a death sentence is inappropriate for a person who suffered a major head injury of a type that impairs the restraint on one’s behaviors.

Most of what I’ve described has been learned very recently. In many cases, we have only just come up with suitable names for how biology can derail a person’s life. As time goes by, there will be more names for more disorders, with more insights into the underlying neu-

robiological traits as well. More mundanely, there is ample reason to fear that such traits will become the basis for denying the “wrong” kinds of people health insurance, fair housing or jobs.

But the scientific progress has to be grounds for optimism as well. As we all gain a few of these labels and diagnoses, something is going to become irrelevant: the hard, confident, judgmental wall that differentiates “health” from “disease.” Get over it. We will have entered a world of medical continua. And when that has happened, the only scientifically justifiable response will have to be a world with more compassion and tolerance.

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Letting constraints filter and guide your thinking can often be the best way to reach truly creative solutions BY IAN AYRES AND BARRY NALEBUFF

Principled Problem Solving

THESE DAYS the popular mantras for stimulating creativity frequently extol the virtues of thinking outside the box: “There are no wrong answers.” “Consider all options.” “Break the boundaries that prevent you from innovating.” But not all boundaries should be broken. Some are real and need to be respected. Sometimes it is best to know how to think creatively *inside* the box.

If you identify constraints that any solution to a specific problem must obey, you can channel your search into more productive directions. Eventually you must always figure out which of your possible solutions are workable and which are not. By imposing constraints on your solution search—in effect, understanding what box they will ultimately have to fit into—you can filter out unworkable ideas before they take shape and see the real solutions more easily.

Becoming aware of the relevant constraints can be powerfully liberating. Filtering out your thoughts this way may at first seem as though it would censor potentially good ideas. But, on the contrary, identifying the underlying attributes of real solutions can actually help generate ideas.

When you are faced with a difficult problem, it’s all too easy to get caught up in what you don’t know. So instead begin by figuring out what you do know about the solution, even if it is incomplete. Identify all the attributes that will be a necessary part of any workable solution. These necessary attributes are the principles (mathematicians call them axioms) that will serve as problem-solving catalysts. A great advantage of this principle-centered approach is that it helps to focus your search by preventing you from having to start from scratch every time you run into a roadblock.

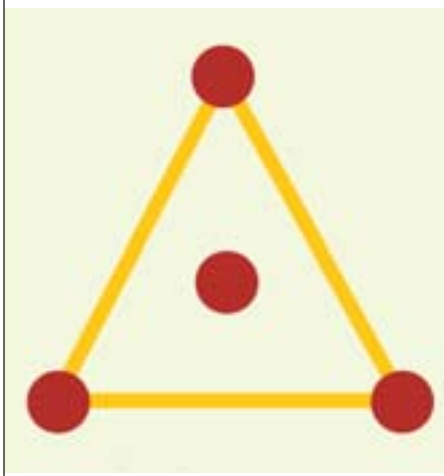
Suppose your task is to plant four seeds so that each is equidistant from the other three. (We learned of this

problem from Edward de Bono’s book *Lateral Thinking: Creativity Step by Step*.) A common first stab at a solution is to plant them at the corners of a



square, but that doesn’t work, because the seeds at opposite diagonals are farther apart. So a complete answer is not immediately apparent.

You do know how to solve part of the problem, however—you can plant three seeds equidistantly by putting



them at the corners of an equilateral triangle. If all four seeds must be equidistant, then so must three of them. Thus, we know one principle: *Three of the seeds must form an equilateral triangle.*

Where does that fourth seed go? Placing it at the center of the triangle doesn’t work. At this point there may be a strong temptation to give up on the triangle—but resist that temptation! The message of principled problem solving is to take what you know to be right and build on it, even if that is not enough to answer the problem.

Given that the first three seeds are relatively fixed in their locations, we can extend our initial principle to say more about where the fourth seed must go. Not only must three of the seeds form an equilateral triangle, but also: *Any three of the seeds must form an equilateral triangle.*

The constraint that isn’t really there, but that we often unconsciously impose, is the requirement that all the seeds lie on a single plane. Putting the fourth seed in the middle would have been right if we could have elevated or lowered it to create equilateral triangles with the seeds at the other corners. The answer that comes to mind, then, is to plant the fourth seed either in a mound or a hole at the center.

Going to three dimensions requires a leap of imagination. But by forcing yourself to hold the first three points in the triangle, you were pushed to give up the false constraint of limiting your answer to two dimensions.

Although such abstract puzzles can be fun, a more important question is whether these same cognitive tools work equally well for solving real-world problems.

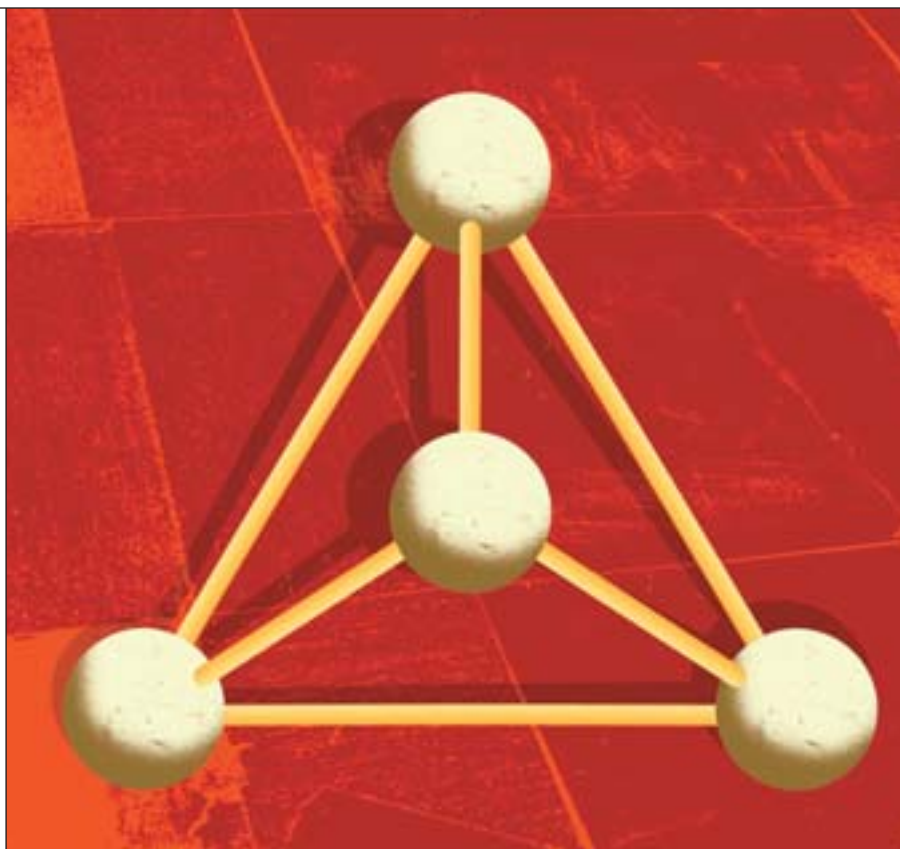
Let’s apply the same principled problem-solving approach to the redesign of a home mortgage. In its most general terms, a mortgage involves a bank (or other financial service provider) lending you some money that you promise to pay back. There are fixed-rate mortgages, floating-rate mortgages and balloon mortgages. All these mortgages have one

common denominator: *The present discounted value of your payments equals the amount that you've borrowed.*

Take the case of a \$100 mortgage and a 10 percent interest rate. You could pay \$10 a year forever, or, alternatively, you could pay nothing the first year and then \$121 in the second year and pay off the mortgage. The bottom line is that the bank needs to get back an amount of money that (in present-value terms) equals the value of what the bankers lent you. This is the first principle of any mortgage solution.

With this principle in mind, let's look at adjustable-rate mortgages. People with a fixed salary and limited liquidity have a real problem borrowing with an adjustable-rate mortgage. They fear that if rates and their monthly payment rise too much, they may no longer be able to afford the mortgage.

The problem is that because most borrowers rely on their salary to make



(The message of principled problem solving is to take what you know to be right and build on it.)

mortgage payments, they cannot take the risk that their monthly payments will go up. Yet when rates rise, the lenders need to get more money in order to restore the value of the loan. Is there a way to give borrowers the benefits of lower rates on adjustable-rate mortgages without exposing them to fluctuations in their monthly payment?

The core principle is that the bank must get the present value of its money back. The conflicting prerequisite is that payments can't rise with interest rates. If we treat the objective of non-fluctuating payments as a constraint, we force ourselves to ask whether we can design an adjustable-rate mortgage that satisfies both constraints.

If we want to keep the monthly payment constant when the interest rate rises, then another term of the loan has to give. That is, something else besides the monthly payment will have to adjust with the market interest rate.

Why not adjust the *number* of payments while holding the amount of each

payment constant? We're not suggesting that the borrower make more frequent payments. Instead extend the life of the mortgage. A 15-year mortgage, for instance, could adjust to become a 16- or 18-year mortgage as interest rates rose.

There are some real constraints on the "adjustable-term" mortgage. Extending the life of the mortgage runs into diminishing returns. Once the mortgage reaches the point at which it would take forever to pay off, the term cannot be extended any further. This constraint need not be a problem, however. Many adjustable mortgages have caps on the maximum possible interest adjustment. Similarly, the term adjustment might be limited to no more than 30 years.

We now have a solution. Would there be any demand for such a product? In fact, in the U.K., these adjustable-term mortgages already exist and have been very popular.

As we've seen, then, principled problem solving offers a way to filter out solutions that are nonstarters. It can also

stimulate creativity by steering us toward answers that might not otherwise have occurred to us.

Of course, principled problem solving can fail if we identify false principles—that is, if we impose artificial constraints on the problem. If a false principle causes us to reject real solutions out of hand, then we may never find an answer. This is why thinking outside the box has such appeal. *Unprincipled* thinking outside the box often fails because it sentences the problem solver to consider any potential solution, no matter how far-fetched.

Thinking outside the box and principled problem solving are, thus, the yin and the yang, the dialectic of efficient innovation. Think of these approaches together as thinking inside the *real* box.

This article is adapted from Why Not? How to Use Everyday Ingenuity to Solve Problems Big and Small, by Barry Nalebuff and Ian Ayres (Harvard Business School Press, 2003).

A Kick in the Head

THE NEW BRAIN: HOW THE MODERN AGE IS REWIRING YOUR MIND

by Richard Restak.
Rodale Press, Emmaus, Pa.,
2003 (\$24)

Pity the poor neurologists of yesteryear, saddled as they were with their conviction that our brains are hardwired after childhood. Then celebrate today's scientists, who are exploiting brain-imaging technologies to show that our brains are capable of profound and permanent alterations throughout our lives. Neurologist Richard Restak does just that in *The New Brain: How the Modern Age Is Rewiring Your Mind*,

even as he argues that we are being negatively altered by the sound-bite, techno environment in which we live.

Technology such as functional magnetic resonance imaging, Restak begins, can now demonstrate that as a musician practices for many hours, certain neural pathways are strengthened. He then moves to a profound implication, namely that all kinds of technological stimuli are forging brain circuits that may hurt us instead of helping us. For instance, he cites correlations between positron emission tomography scans of violent people and normal experimental subjects who are simply thinking about fighting, then

asserts that repeated viewing of violence on television and in video games can set up brain circuits that make us more likely to initiate real-world fisticuffs.

Unfortunately, such brain imaging may leave more questions than answers. As Restak himself points out, the technology does not provide "neurological explanations," just "important correlations." Yet he is whipped up enough to diagnose all of modern society with attention-deficit hyperactivity dis-

order, the probable result of brain changes we are initiating in our media-saturated world. He reminds us of the antidote, though: we are still in control of what we allow ourselves to see and hear.

In the end, Restak fails to create a sense that scientists have revealed a new way of understanding the brain. And the images that inspire speculation in the book still await research that may finally reveal the mechanisms of such phenomena as memory and aggression.
—Chris Jozefowicz



Mind Reads

Too Painful to Recall?

REMEMBERING TRAUMA

by Richard J. McNally. Belknap Press
of Harvard University Press, Cambridge,
Mass., 2003 (\$35)

Many science books earn praise for taking a topic that the public might consider dull or irrelevant and turning it into a fascinating drama. But there is something to be said for doing the opposite—stripping down a controversial topic to the science at its core.

"How victims remember trauma is the most divisive issue facing psychology today," writes Harvard University psychologist Richard J. McNally in the opening lines of *Remembering Trauma*. It is also central to headlines about whether men are accurately portraying childhood abuse by their clergy.

McNally quickly summarizes the history of the repressed-memory

debate to help readers frame the science he later presents. The issue first became big in the 1980s, when therapists began to diagnose sufferers of depression and other mental health problems as victims of childhood sexual abuse, the memories of which were said to be repressed as a defense mechanism against reliving the pain. Reports of recovered memories of sexual abuse peaked in the mid- to late 1990s and were followed by a backlash from accused family members who denounced what they

called false-memory syndrome. Practitioners of recovered-memory therapy defended their methods, even as some patients retracted their claims of abuse and sued their former therapists.

At the same time, extensive clinical research on the nature of memory and trauma was being conducted. Indeed, McNally's analysis of it

makes up the bulk of the book. From simple word-memorization experiments in the laboratory to interviews with Vietnam veterans suffering from post-traumatic stress disorder, the author summarizes dozens of studies while providing clear explanations of psychological concepts and expert insight into the strengths and limitations of the findings. The overwhelming evidence leads him to conclude that people do not forget experiences that were truly traumatic. Although some victims can go for long periods without thinking of past events, this should not be confused with an inability to remember their ordeals. Even though at times McNally may overgeneralize, he ultimately debunks theories of repressed memory and the "trauma industry" that has sprouted to cater to this purported condition. Although his exhaustive recounting of cases may be tedious for casual readers, those with an interest should appreciate the wealth of information and McNally's sober approach to this emotionally charged subject.
—Daniel Cho



Last Mystery

CONSCIOUSNESS: AN INTRODUCTION

by Susan Blackmore. Oxford University Press, New York, 2003 (\$40, paperback)

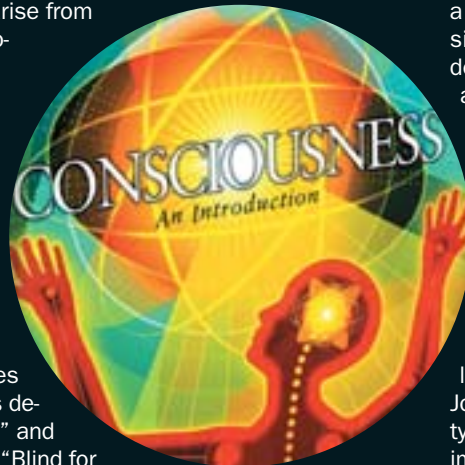
If you've ever driven along a highway and suddenly realized that you have no memory of how you just got to a certain point, then you have some idea of what it's like to be "in" and "out" of consciousness. Understanding the difference is the crux of *Consciousness: An Introduction*, which examines the scientific nature of subjective experience.

Susan Blackmore, a former lecturer in psychology at the University of the West of England in Bristol, casts a wide net in exploring what she calls "the last great mystery of science." She painstakingly documents the evolution of consciousness studies, from the pioneering work of William James to the controversial, contemporary work of Daniel C. Dennett of Tufts University, who

maintains that consciousness is a complex of "memes"—verbal and written information that is transferred from person to person. Then she marches through a host of other topics, including how subjective experiences arise from objective brain processes; altered states; and mystical experiences and dreams.

To offset this weightiness, Blackmore periodically invites the reader to participate in interesting practice exercises with titles such as "Was this decision conscious?" and activities such as "Blind for an hour" that sharpen self-awareness. "Some of you will enjoy the self-examination and find the science and philosophy hard," she writes of her approach. "Others will lap up the science and find the personal inquiry troubling or trivial. I can only say this: both are

needed." Blackmore also strikes a balance in showing how Western and Eastern philosophies view consciousness. Parts of this discussion may seem too difficult to grasp, but she is



not after black-and-white conclusions; she is bold enough to leave some questions unanswered.

Blackmore's best chapters come in the latter part of the book. Her analyses of the effects of brain damage on consciousness are

fascinating in their human detail. She does get sidetracked by devoting three short chapters to the possibility of consciousness in robots, even though a machine's total lack of subjectivity would appear to make a prolonged analysis beside the point. But she redeems herself with an amusing anecdote that underscores how even the best-intentioned scholars can get carried away by their own theories. When computer scientist John McCarthy of Stanford University claimed that his thermostat had a belief system, philosopher John Searle of the University of California at Berkeley immediately asked, "John, what beliefs does your thermostat have?" McCarthy's reply was both clever and courageous: "My thermostat has three beliefs. My thermostat believes that it's too hot in here, it's too cold in here and it's just right in here."

—Robert Rorke

Economics 101

DECISIONS, UNCERTAINTY, AND THE BRAIN: THE SCIENCE OF NEUROECONOMICS

by Paul W. Glimcher. MIT Press, Cambridge, Mass., 2003 (\$38)

The notion that the brain and central nervous system are made of circuits that process stimuli and evoke bodily responses is a founding principle of neuroscience. And we humans believe that once we understand every neural pathway, we will be able to predict a motor response to every sensory input—from feeling the tug of a fish on a hook to catching your spouse in bed with someone else. All we have to do is build the right deterministic model of the brain.

In *Decisions, Uncertainty, and the Brain: The Science of Neuroeconomics*, Paul W. Glimcher, an associate professor of neural science and psychology at New York University, recounts how the history of neuroscience has brought hu-

mankind to this reflex-based model—and then explains why it is insufficient. Simple behaviors might arise from stimulus-response rules, he allows, but complex behaviors are far less predictable. For example, the brain can weigh value and risk, even with incomplete or uncertain information.

But how? Fortunately, Glimcher points out, there is already a science to answer that question: economics, particularly game theory. Other scientists have tapped economic theory to explain the natural world. In the 1960s certain ecologists used the discipline to model how animals forage for food and choose a mate. Glimcher makes a case that "neuroeconomics" can complete our understanding of our brains. He cites his own experiments on humans and monkeys to show how economic principles can accurately represent intricate thought processes, in situations rife with competing values and interests.

As the book proceeds, the going

can get tough, but the historical insight is worth the trip. Readers may feel a bit unsatisfied when Glimcher notes that a unified theory of neuroeconomics has yet to be written and then admits that he doesn't know what this theory would look like. Yet he rises to the occasion by suggesting how scientists could begin to apply neuroeconomics to define the optimal course of action that a person might select and by providing a mathematical route for deriving that solution. In this way, Glimcher says, scientists can devise a better understanding of how the brain makes complex decisions in an uncertain world.

—Dennis Watkins



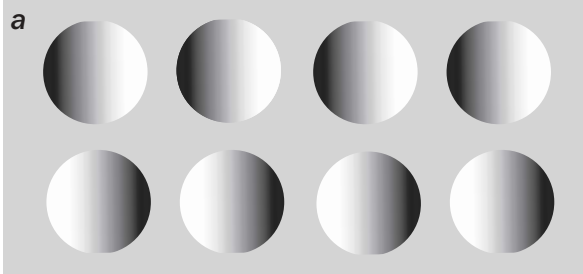
2-D or not 2-D, that is the question: test yourself to learn what shapes formed by shading reveal about the brain **BY VILAYANUR S. RAMACHANDRAN AND DIANE ROGERS-RAMACHANDRAN**

Seeing Is Believing

THE VISUAL IMAGE is inherently ambiguous: an image of a person on the retina would be the same size for a dwarf seen from up close or a giant viewed from a distance. Perception is partly

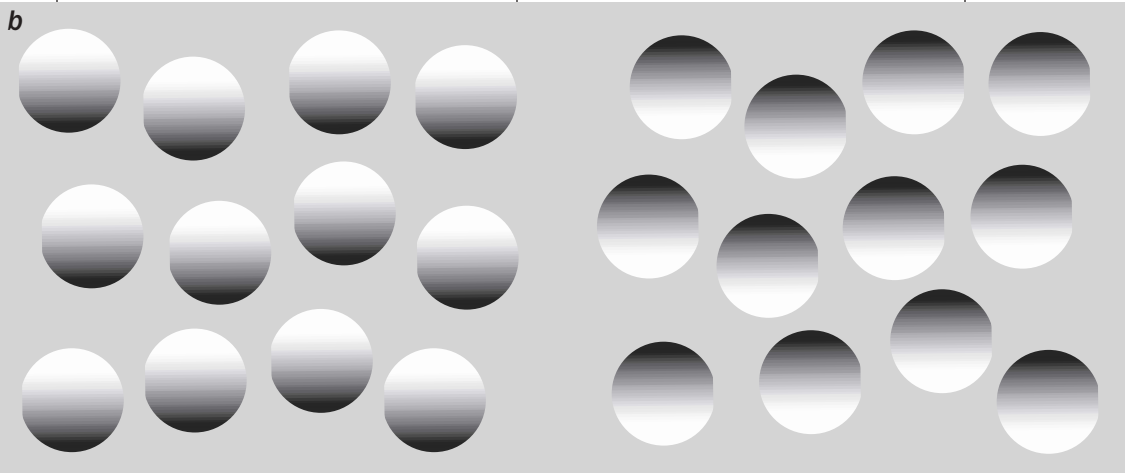
a matter of using certain assumptions about the world to resolve such ambiguities. We can use illusions to uncover what the brain's hidden rules and assumptions are. In this column, we consider illusions of shading.

In (a), the disks are ambiguous; you can see either the top row as convex spheres or "eggs," lit from the left, and the bottom row as cavities—or vice versa. This observation reveals that the visual centers in the brain have a built-in supposition that a single light source illuminates the entire image, which makes sense given that we evolved on a planet with one sun. By consciously shifting the light source from left to right, you can make the eggs and cavities switch places.



In (b), the image is even more compelling. Here the disks that are light on the top (left) always look like eggs, and the ones that are light on the bottom (right) are cavities. So we have uncovered another premise used by the visual system: it expects light to shine from above. You can verify this by turning the page upside down. All the eggs and cavities instantly switch places.

Amazingly, the brain's assumption that light shines from above the head is preserved even when you rotate your head 180 degrees. Ask a friend to hold this page right side up for you. Then bend down and look between your legs at the page behind you. You will find that, again, the switch occurs, as if the



sun is stuck to your head and shining upward from the floor. Signals from your body's center of balance—the vestibular system—guided by the positions of little stones in your ears called otoliths, travel to your visual centers to correct your picture of the world (so that the world continues to look upright) but do not correct for the location of the sun.

From this experiment we learn that despite the impression of seamless unity, vision is actually mediated by multiple parallel information-processing modules in the brain. Some of the modules connect to the vestibular system; however, the one that handles shape from shading does not. The reason might be that correcting an image for placement in so-called world-centered coordinates would be too computationally expensive and take too much time. Our ancestors generally kept their heads upright, so the brain could get away with this shortcut (or simplifying assumption). That is, our progenitors were able to raise babies to maturity often enough that no selection pressure acted to produce vestibular correction.

If you look at (c), you find that you can almost instantly mentally group all the eggs and segregate them from the cavities. As visual scientists discovered decades ago, only certain elementary features that are extracted

early during visual processing "pop out" conspicuously and can be grouped in this manner. For example, your brain can discern a set of red dots in a background of green ones but cannot group smiles scattered among a backdrop of frowns. Color is thus a primitive feature that is extracted early, whereas a smile is

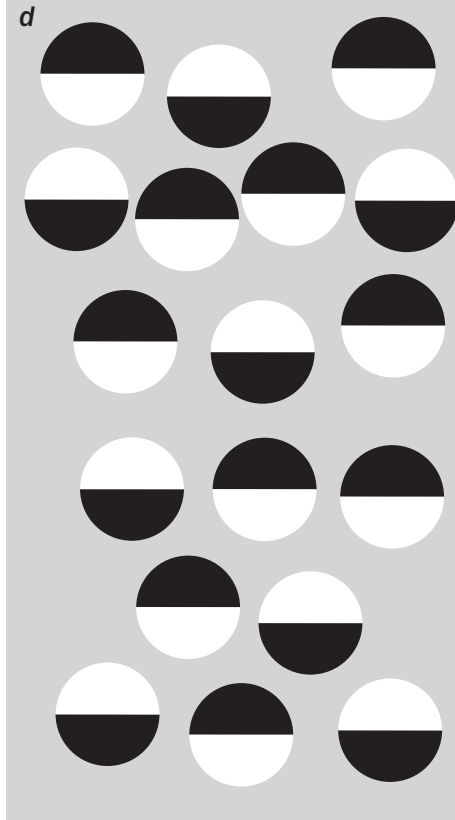
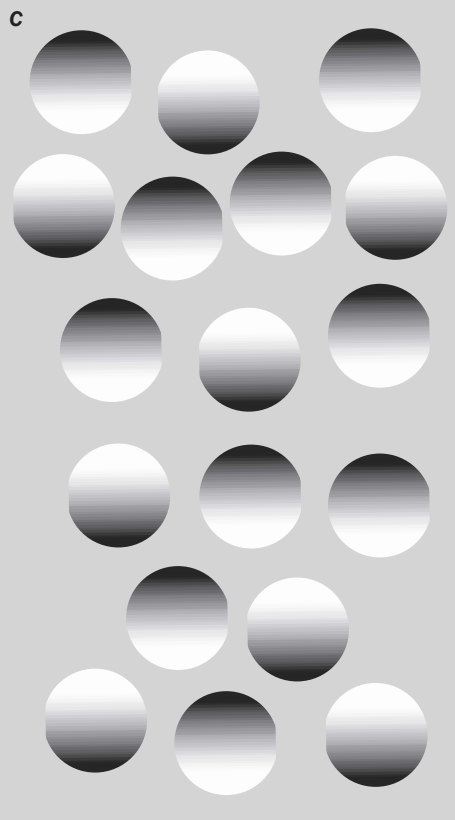
Perception is partly a matter of using certain **assumptions about the world to resolve ambiguities.** We can use illusions to uncover the brain's hidden rules.

Of course, over millions of years, evolution has “discovered” and taken advantage of the principles of shading that researchers have explored only lately.

not. (It makes survival sense to be able to piece together fragments of similar color. A lion hidden behind a screen of green leaves is visible merely as gold fragments, but the visual brain assembles the pieces into a single gold lion-shaped form and warns: “Get out of here!” On the other hand, objects are not made up of smiles.)

The fact that you can group the eggs in (c) implies that shading information, like color, is extracted early in visual processing [see “Perceiving Shape from Shading,” by Vilayanur S. Ramachandran; *SCIENTIFIC AMERICAN*, August 1988]. This prediction was verified in recent years by recording activity in the neurons of monkeys and by conducting brain-imaging experiments in humans. Certain cells in the visual cortex fire when the observer sees eggs; others respond only to cavities. In (d), where the circles have the same luminance polarities as in (c), you cannot perceive the grouping; this fact suggests the importance of perceived depth as a cue that is extracted early in visual processing.

Of course, over millions of years, evolution has “discovered” and taken advantage of the principles of shading that researchers have explored only lately. Gazelles have white bellies and dark backs—countershading—that neutralize the effect of sunshine from above. The result reduces pop-out so that gazelles are not as conspicuous; they also appear skinnier and less appetizing to a predator. Caterpillars have countershading, too, so they more closely resemble the flat leaves on which they munch. One caterpillar species has *reverse* countershading—which did not make sense until scientists realized that the insect habitually hangs upside down from twigs. One type of octopus can even invert its countershading: if you suspend the octopus upside down, it uses pigment-producing cells called



chromatophores in the skin, which are controlled by its vestibular input, to reverse its darker and lighter areas.

Charles Darwin noticed a striking example of nature’s use of shading in the prominent eyelike spots on the long tails of argus pheasants. With the tail feathers at horizontal rest, the orbs are tinged from left to right. During the bird’s courtship display, however, the tail feathers become erect. In this position, the spots are paler on top and dusker at bottom, so the disks seem to bulge out like shiny metallic spheres—the avian equivalent of jewelry.

That a few simple shaded circles can unveil the underlying assumptions of our visual systems—and even how such

principles have played a role in shaping evolutionary adaptations—shows the power of visual illusions in helping us to understand the nature of perception.

VILAYANUR S. RAMACHANDRAN and DIANE ROGERS-RAMACHANDRAN collaborate on studies of visual perception at the Center for Brain and Cognition at the University of California, San Diego. Ramachandran is author of *Phantoms in the Brain*. Among his honors are a fellowship at All Souls College of the University of Oxford and the Ariëns Kappers medal from the Royal Netherlands Academy of Arts and Sciences. He gave the 2003 BBC Reith lectures. Rogers-Ramachandran was a researcher at the University of North Carolina at Chapel Hill before moving to U.C.S.D.

(Further Reading)

- ◆ **On the Perception of Shape from Shading.** D. A. Kleffner and V. S. Ramachandran in *Perception and Psychophysics*, Vol. 52, No. 1, pages 18–36; July 1992.
- ◆ **Neural Activity in Early Visual Cortex Reflects Behavioral Experience and Higher-Order Perceptual Saliency.** Tai Sing Lee, Cindy F. Yang, Richard D. Romero and David Mumford in *Nature Neuroscience*, Vol. 5, No. 6, pages 589–597; June 2002.