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SCIENTIFIC AMERICAN
MIND
BEHAVIOR • BRAIN SCIENCE • INSIGHTS

August/September 2008 www.SciAmMind.com

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Mental Error Correction
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How the sleeping brain builds memories and solves problems

Preventing Depression
Mind-Healthy Hobbies

The Power of Stories
Why They Transport Us

Brainy Animals
What They Know

PLUS:
Keys to Higher IQs
Biology of Brilliance

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PHOTOILLUSTRATION BY AARON GOODMAN; SHUTTERSTOCK (*woman*); GETTY IMAGES (*scenes inside film*)

Emotional Ties

Macbeth extolled "sleep that knits up the ravell'd sleave of care," in Shakespeare's great tragic play of the same name. Soothing rest is not all that shut-eye provides, however. As sleep and cognition researchers Robert Stickgold and Jeffrey M. Ellenbogen explain in their feature article in this issue, the brain is very busy during a night's slumber. It is processing and sorting all the things we learned during the day, making valuable memories more resilient and tossing away irrelevant details. It finds hidden relations among our recollections and works to solve problems that arose during our waking hours. Turn to page 22 for our cover story, "Quiet! Sleeping Brain at Work."

While we are catching some zzz's, the brain preferentially strengthens memories that have important emotional content. A humming emotional-rewards circuit is also key to warding off depression in many of us, as neuroscientist and psychologist Kelly Lambert explains in "Depressingly Easy." Activities that stir our thinking, motor and pleasure centers—such as gardening, cooking, knitting—engage the brain in ways that make us mentally healthier, Lambert explains. Anticipating the ultimate result as we perform such laborious tasks can be more enjoyable than achieving the end goal itself. The swift ease of modern, push-button conveniences, in contrast, may undercut our brain's supply of hard-earned rewards, making us more susceptible to depression. Find out why starting on page 30.

There is nothing like a good yarn to pluck our emotional strings, as Jeremy Hsu writes in "The Secrets of Storytelling," beginning on page 46. Stories are one of humanity's universals—they appear in all cultures—and certain themes arise repeatedly in tales around the world. Why do these narratives have such power over our feelings? The study of stories reveals clues about our evolutionary history and the roots of emotion and empathy. Indeed, as you will learn from Hsu's article, the stories we tell explain much about ourselves.

Mariette DiChristina
Executive Editor
editors@SciAmMind.com

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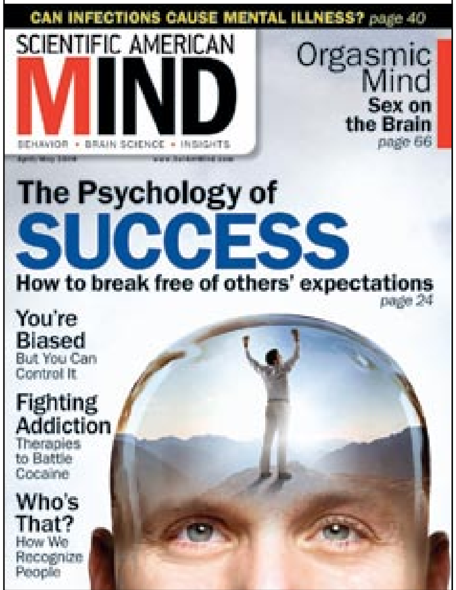


HARDLY BLACK AND WHITE

In "The Social Psychology of Success," by S. Alexander Haslam, Jessica Salvatore, Thomas Kessler and Stephen D. Reicher, it seems the authors' bar graphs concerning blacks' perceptions of inferiority are adding to problems inherent in group comparisons. The flat tops of the graphs on page 27 imply that all whites are smarter than all blacks. Each bar should actually be a compressed bell curve, showing that only a small percent of whites have superior intelligence and that many blacks are smarter than many whites.

Dan Robinson
Eugene, Ore.

JUSTIFIED PREJUDICE?

Siri Carpenter's "Buried Prejudice" opens with a quote from Jesse Jackson about hearing a pedestrian's footsteps behind him and feeling relief when he notices that his follower is white. The quote was a good opener, but it was quickly dropped without a thorough examination. Dinesh D'Souza's book *The End of Racism* (Free Press, 1995) contains a deeper analysis, ending with a most pertinent point: "Given the crime rates of young black males, 'the stereotype is not a stereotype any more,' says Howard University education professor Kenneth Tollett. 'A stereotype is an overgeneralization. The statements we have called stereotypes in the past have become true.'"

Accordingly, I found most interesting the views expressed in your article by Northwestern University psychologist Jennifer A. Richeson, who speculates that our brains may automatically give preferential attention to blacks as a category, just as they do for threatening animals such as snakes.

That idea will surely provoke a negative response from those who see prejudice on her part for likening young black men to snakes, but I see a perfect analogy: it is wise to fear what is dangerous. Thousands of people die every year from snakebites. Thousands are victims of the criminal acts of young black men, one out of four of whom have a criminal record. Is it prejudice to reason rationally and logically? It certainly has become politically incorrect.

Jeffry L. Smith
via e-mail

CARPENTER REPLIES: Many people find this line of reasoning persuasive, but it is incomplete. It is unfair to judge an individual based solely on his or her group membership, and such presumptions of guilt by association do not promote accuracy in decision making. For example, although blacks are arrested and incarcerated in disproportionate numbers, the majority of people of all races are law-abiding citizens. To assume that a randomly chosen black person is probably a criminal would be erroneous and unjust.

We all use statistical base rates to guide our decisions. For example, we use a person's age and gender to set car insurance premiums, and we usually include only women in breast cancer research, even though men can develop the disease. But this statistical reasoning has both costs and benefits. Before deploying a stereotype to judge another person, we need to weigh the trade-offs. What do whites gain if we assume black men are dangerous? What do we as a society—not to mention innocent black men—lose when we're wrong? As work *on implicit bias shows, the presence of stereotypes of which we may not be aware means that we are in the unhappy position of relying on stereotypes even when we don't want to.*

A POOR CHOICE

I wonder why you used a picture of Senator Barack Obama in Kurt Kleiner's article "In Your Face" [Head Lines]. The article rightly reveals that the "shouting heads" of television news affect our views partly because of the extreme close-up position of the cameras. But why didn't you use a picture of one of the actual confrontational political commentators? Bill O'Reilly, perhaps?

The editors should take a moment to read the opening statement of Siri Carpenter's excellent article: "Deep within our subconscious, all of us harbor biases that we consciously abhor. And the worst part is: we act on them." You managed to demonstrate how an implicit racial bias, "black people are loud and angry," can become an explicit choice. Obama may have many character traits that affect his likability. I do not think, however, anyone can characterize him as loud, angry and rude.

Ra'ayah Turnbull
Brooklyn, N.Y.

FLYING HIGH

R. Douglas Fields's "Brain Cells Into Thin Air" [Perspectives] is most interesting when you consider that a pressurized aircraft cabin is standardized to 8,000 feet (2,440 meters). Passengers are taken to that altitude rather quickly.

"harriev"
adapted from a comment at www.SciAm.com

FIELDS REPLIES: *The dangers of hypoxia in aviation are well known, and in many situations they are not subtle.*

Healthy individuals on a normal commercial flight will experience a significant decrease in blood oxygen, according to a 2006 study in the journal Aviation, Space and Environmental Medicine. *A 2004 study in the same journal found that the amount of oxygen decreases in proportion to a person's age, but in 2002 other researchers had reported in* Pediatric Emergency Care *that children also experience effects of hypoxia, including an increased heart rate.*

People with preexisting conditions are at risk for serious injury when they fly. In 2006 Ludvic Zrinzo and his colleagues reported two relevant cases in the Journal of Neurosurgery. *A 22-year-old man, who was fine until he flew, returned from a flight with a headache, which quickly developed into severe neurological problems that resulted in a coma. The second case concerned a 55-year-old woman who was also well until she flew. She suffered such severe brain injury from a commercial airline flight that she died 24 hours later.*

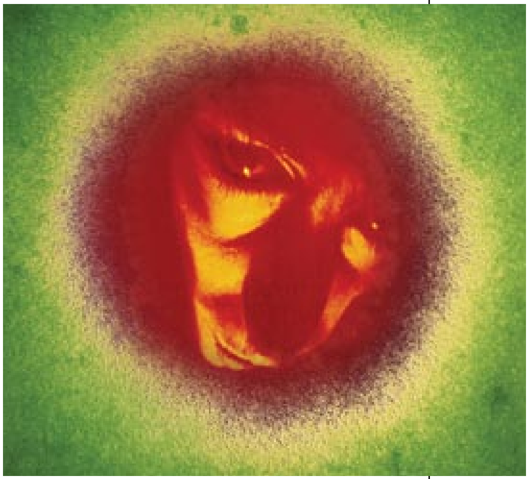
As in climbing, the standards for airline safety are focused on preventing sudden illness. No one gets a brain scan if he or she does not feel sick. Yet only one of 13 Everest climbers return from the summit with a normal brain scan. There is one crucial difference between climbing and flying, however: nobody can change the air pressure on a mountaintop. Why are we flying around hypoxic at 8,000 feet?

Editors' note: *Fields's original, longer comment—and his responses to many other hypoxia-related queries—can be found here:* ***www.SciAm.com/article.cfm?id=brain-cells-into-thin-air***

THE STRESS FACTOR

I enjoyed Melinda Wenner's article, "Infected with Insanity." I was a bit disappointed, however, that she made no mention of the role of stress and its influence on influenza infection and immune system function. Yes, microbes may have an effect on the developing brain, but what about the stressed-out soon-to-be mother?

I find it amusing that prescription drugs are promoted as a possible solution when something much more fundamental may be at fault—how well the expectant mother is able to cope with stress. If that ability plays a role, perhaps mothers' coping skills could be developed, reducing the risk of low immune function and avoiding adverse side effects altogether.



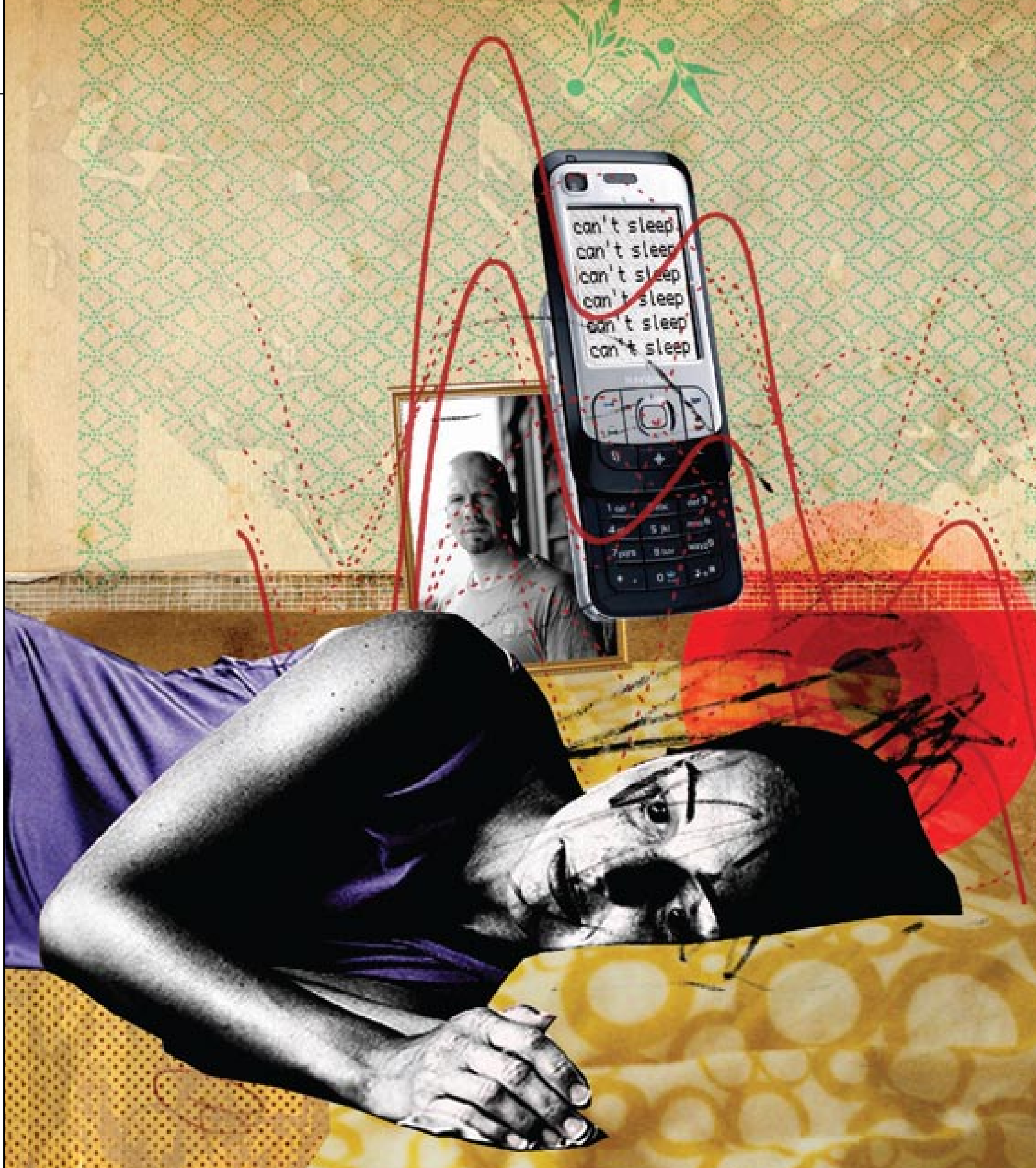
Maternal stress can influence a child's behavior and mental health.

William Lu
via e-mail

WENNER REPLIES: *Lu is correct. A number of studies suggest that maternal stress can affect the development of fetal neurons and influence a child's behavior and mental health. Christopher Coe, the University of Wisconsin–Madison psychologist whose work on prenatal infections I mentioned in my article, also studies how stress affects fetal development. An overview of related research can be found in* Perinatal Programming: Early Life Determinants of Adult Health & Disease *(Informa Healthcare, 2005), a book Coe co-edited with University of Newcastle psychologist Deborah Hodgson.*

NIBSC/SPL/PHOTO RESEARCHERS, INC. *(influenza particles)*; MEHAU KULYK *Photo Researchers, Inc. (face)*

Head Lines



MICHELLE THOMPSON

>> HEALTH

Call Me Sleepless

Using a mobile phone just before bed may cause insomnia

Many of us enjoy an occasional bedtime chat with a loved one who is far away. But as more and more people trade in their landlines for mobile phones, they may find that these late-night conversations are no longer a good idea. According to recent studies, cell phone signals can alter brain waves—and the consequences will keep you up at night.

Neuroscientist Rodney Croft and his colleagues at Swinburne University of Technology in Australia strapped a Nokia 6110 cell phone to the heads of 120 men and women and then monitored their brain waves. When the researchers switched on the phone without the subjects' knowledge, they saw a sudden power boost in the volunteers' alpha brain waves. Alpha waves normally surge as the mind shuts out the external world and spins internal thoughts. Croft believes the heightened alpha waves reflect the mind concentrating to overcome the electrical interference in brain circuits caused by the pulsed microwave radiation from cell phones.

In a different study, sleep researchers at Loughborough University in England found that after a 30-minute exposure to cell phone signals in talk mode, people took nearly twice as long to fall asleep as they did when the phone had been off or in standby mode. The scientists think the effect probably reflects the time it takes the brain to relax after being agitated by the phone's electrical field.

James Horne, one of the study's authors, cautions that the effects are harmless and less disruptive to sleep than half a cup of coffee. Still, he wonders, "With different doses, durations or other devices, would there be greater effects?" *—R. Douglas Fields*

>> ADDICTION

Ease Anxiety, Curb Cravings

Blocking a stress mechanism in the brain diminishes alcohol urges

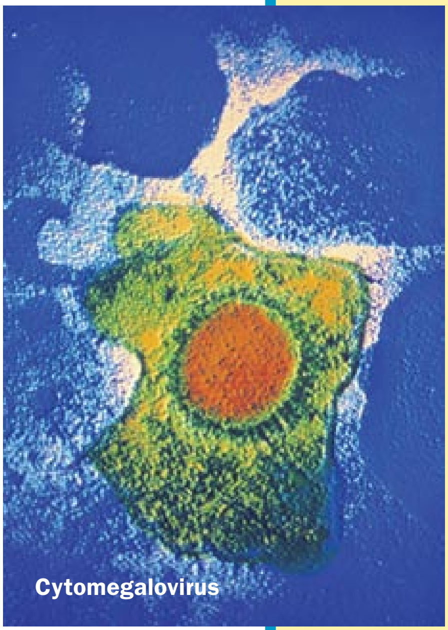
Once an alcoholic, always an alcoholic—the saying is decades old, but scientists have only recently uncovered why it is often true. Long-term alcohol abuse changes the brain, making a person more sensitive to stress and more likely to reach for the bottle to soothe his or her anxiety. According to a new study, drugs that inhibit these stress pathways could help recovering alcoholics stay in control.

Scientists at the National Institutes of Health and University College London bred mice lacking the neurokinin 1 receptor (NK1R), a protein involved in the brain's stress response. The mice were given unlimited access to alcohol-spiked water for 60 days, during which the alcohol content was incrementally raised from 3 to 15 percent. The NK1R-deficient mice consumed far less alcohol—especially later in the trial when alcohol concentration was higher—than the normal mice did. They were also more sensitive to alcohol's effects than the normal mice were; studies have shown that the more sensitive a person is to alcohol, the less likely he or she is to abuse it.

The team then treated 25 highly anxious recovering alcoholics with a drug that blocks the NK1 receptor. After four weeks of hospital treatment, the subjects taking the drug reported fewer spontaneous and stress-induced alcohol cravings than patients given a placebo did. When the scientists used functional MRI to look at the subjects' brain activity, they found that the treated subjects showed less activity in the insula, a region associated with craving. The scientists believe the drug targets a stress pathway specific to alcoholics because it has been shown to have little effect on stress levels in other types of patients.

Lead author Markus Heilig of the NIH cautions that although the study is promising, it does not prove that the drug will help alcoholics long-term. Scientists "need to do studies in outpatients and look at reduction in drinking," he says. A larger clinical trial designed to do just that will begin recruiting subjects later this year.

—Melinda Wenner


Cytomegalovirus

>> MEDICINE

Does Herpes Cause Brain Cancer?

Targeting a common virus staves off tumor regrowth

The deadliest and most common type of brain cancer has a strange bedfellow: cytomegalovirus, a kind of herpes present in about 80 percent of the U.S. population. Now scientists are exploiting this coincidence to treat the cancer with a vaccine that targets the virus and slows tumor regrowth.

In 2002 scientists showed that cytomegalovirus, or CMV, was active in the brain tumors but not the surrounding healthy tissue of all 27 patients they tested who had glioblastoma multiforme. CMV is dormant and undetectable in most people.

Neuroscientist Duane Mitchell of Duke University Medical Center and his colleagues confirmed in 2007 that CMV is active in at least 90 percent of glioblastoma tumors. Now Mitchell's team has developed an experimental vaccine that triggers the immune system to attack CMV, thereby attacking its tumor tissue home. As reported at the American Society of Clinical Oncology meeting earlier this year, the vaccine, together with radiation and chemotherapy, prevented the brain tumor from reemerging after surgery for 12 months as compared with the typical six to seven months with no vaccine. Patients' average life span increased from 14 months to more than 20.

So does this herpesvirus cause cancer? The answer is unclear: tumor cells may simply be a fertile ground for growing the virus, as cells such as these often lack the normal immune functions that suppress CMV reproduction. But University of Wisconsin–Madison researchers reported in May that the virus has the ability to take over a cell's braking mechanism and cause uncontrolled reproduction. Even so, the numbers do not seem to add up: four of five Americans has CMV, but only about one in 30,000 ends up with glioblastoma. And a small number of glioblastoma patients do *not* have CMV in their tumors.

"Most evidence to date does not support CMV being a cancer-causing virus," Mitchell says. Don Diamond, a virologist at the City of Hope Cancer Center near Los Angeles, agrees: his extensive research on CMV and cancer has convinced him the virus does not cause tumors. But for patients it does not matter whether the connection between herpes and brain cancer is causal or not—the vaccine appears to work. Mitchell hopes to have the vaccine ready for market in a few years.

—Victoria Stern

JUPITERIMAGES (top); INSTITUT PASTEUR, UNITE DES VIRUS ONCOGENES SPL/Photo Researchers, Inc. (bottom)

>> BEHAVIOR

Rooks Take Food

Two birds can work together to secure a treat

Birds of a feather don't just flock together—they also work together to obtain food. New research makes rooks the first nonprimates observed to successfully cooperate to retrieve a food-laden platform.

Scientists at the University of Cambridge tested the rooks, which are Eurasian members of the crow family, by placing dishes of food on a platform out of reach of a bird enclosure. A single string looped from the enclosure to the platform and back again. Moving the platform closer required pulling on both ends of the string simultaneously, a feat that is only possible if two birds work together, each tugging on one end.

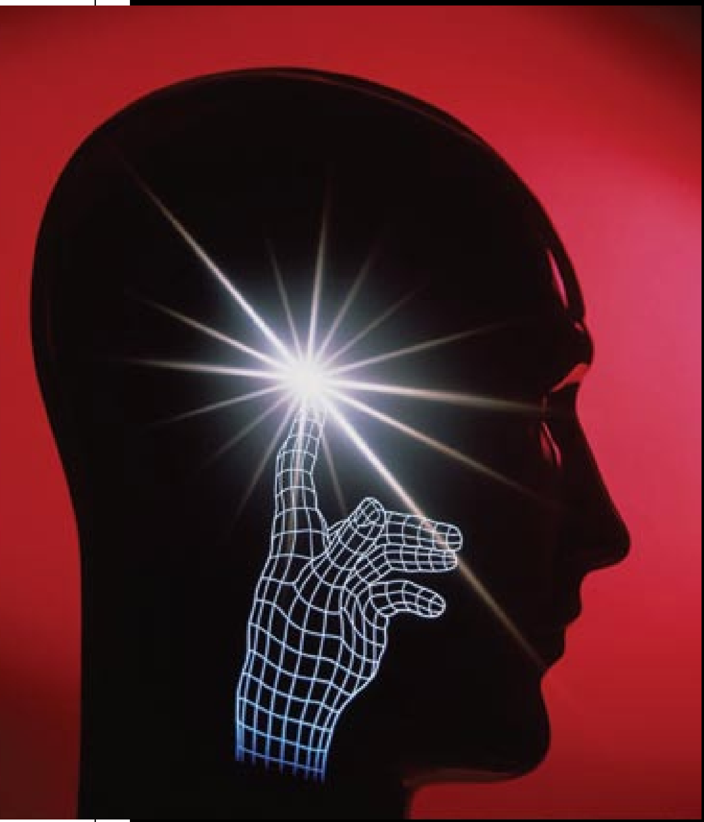
The researchers found that rook pairs spontaneously learned how to solve the problem. "We were amazed that the rooks performed so well," says lead author Amanda Seed, now at the Max Planck Institute for Evolutionary Anthropology in Leipzig, Germany. "It's really hard to coordinate your actions. If you wait an extra second, you miss your chance."

Chimpanzees, and possibly a few other primates, are the only other species that have proved themselves capable of the same task. Rooks are extremely social birds, living in colonies of hundreds of members, and are likely to have faced evolutionary pressure to learn to cooperate, Seed says.

Further investigation, however, revealed that the rooks may not have as sophisticated an understanding of the task as apes seem to have. Previous research has shown that once a chimp learns it needs a partner to move the platform, it will no longer attempt the task if it is alone. The rooks in Seed's lab, on the other hand, kept trying (and failing) to move the platform alone, even after successfully obtaining the food with a partner.

Seed theorizes that these results may stem from the differences between rook and chimp communities. Although rooks are social birds, they are monogamous and mate for life, making for a relatively stable adult rook society. Chimps, on the other hand, are polygamous, which makes relationships complicated, variable and difficult to negotiate. As a result, Seed says, chimps may have faced evolutionary pressure to develop a more sophisticated understanding of cooperation, competition and social relationships than rooks have.

—*Emily Anthes*



>> NEUROSCIENCE

Unconscious Decisions

As we mull a choice, our subconscious decides for us

What are you going to do after you read this story? You may not know that yet, but your brain probably does. A new study shows that patterns of brain activity can reveal which choice a person is going to make long before he or she is aware of it. A team led by John-Dylan Haynes of the Bernstein Center for Computational Neuroscience Berlin scanned the brains of volunteers who held a button in each hand and were told to push one of the buttons whenever they wanted to. The scientists could tell from the scans which hand participants were going to use as early as 10 seconds before the volunteers were aware that they made up their mind.

Previous research has shown motor-related brain activity preceding conscious intent by a fraction of a second, but this study is the first to show unconscious predictive activity in a region associated with decision making—the prefrontal cortex—according to Haynes. The results support the notion that unconscious brain activity comes first and conscious experience follows as a result, says Patrick Haggard of University College London, who was not involved with the study. "We all think that we have a conscious free will," he says. "However, this study shows that actions come from preconscious brain activity patterns and not from the person consciously thinking about what they are going to do."

—*Nicole Branan*

PIET MUNSTERMAN *Minden Pictures* (*top*); TONY CRADDOCK *SPL/Photo Researchers, Inc.* (*bottom*)

>> ANXIETY

Mass Appeal

Incense may act as an antidepressant

Pope Benedict XVI releases incense.

Burning incense has accompanied religious ceremonies since ancient times. Its fragrant presence may be more than symbolic, however—a new study suggests that a chemical commonly found in incense may elevate mood.

Raphael Mechoulam of the Hebrew University of Jerusalem and his colleagues injected mice with incensole acetate, a component of the resin of the *Boswellia* plant. This resin, better known as frankincense, is an ingredient in Middle Eastern incense. The chemical reduced anxiety and depressive symptoms in the mice. In the anxiety test, for example, injected animals were less fearful of open spaces as compared with mice that were given a placebo.

Incensole acetate is a mild drug: the chemical proved to be 10 times less potent than Valium in its reduction of anxiety, Mechoulam says. During religious ceremonies, the people inhaling the most smoke—the officiants burning the incense—are probably the only ones who feel its effects, he adds. Incensole acetate may lead to new treatments for anxiety and depression if more potent forms can be synthesized and if it successfully lifts moods in human trials.

—Aimee Cunningham

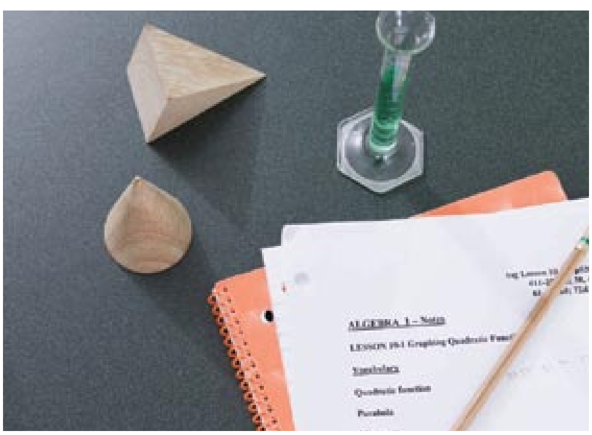
>> LEARNING

Word Problems

Traditional story setups might hinder math learning

Jane has $3.05 in nickels and quarters. If she has 13 more nickels than quarters, how many coins does she have? According to the conventional thinking, real-world examples such as this one are the best way to teach mathematics. When researchers at Ohio State University tested this hypothesis, however, they found the opposite to be true. They showed college students a mathematical pattern using either a concrete example (in this case, measuring cups filled with water) or an abstract example involving symbols, then had them play a game that drew on their new skills. The subjects who saw the abstract example performed significantly better in the game than did those who learned the pattern with measuring cups. Jennifer Kaminski, lead author of the study, hypothesizes that real-world examples might distract students from the mathematics being represented. "We think what's driving this is attentional focus," she says. (And by the way, Jane has 29 coins.)

—Erica Westly



FRANCO ORIGLIA *Getty Images* (*top*); AGE FOTOSTOCK (*bottom*)

Psychotherapy sessions seem to help fictional mob boss Tony Soprano, but for viewers of HBO's *The Sopranos* these depictions of therapy may diminish their desire to seek it in their own lives. Psychologists at Iowa State University found that people who watched television characters undergo treatment came away with negative perceptions of talk therapy. The stigma was largely the result of TV's unflattering portraits of patients and therapists, according to the researchers.

Sleepiness can provoke a "power failure" in the brain, report neuroscientists at Duke–National University of Singapore Graduate Medical School. The researchers tested volunteers on a simple visual task while scanning their brains with functional MRI. They found that the brains of people who had been kept awake all night fluctuated occasionally from normal activity to so-called power-failure mode, in which subjects experienced suddenly diminished control over cognitive and visual centers for a few seconds.

Looking at food triggers hunger, and the culprit seems to be a gut hormone called ghrelin, which encourages eating and activates reward regions in the brain. McGill University neurologists used fMRI to measure the brain's response to food and nonfood images. People who received an injection of extra ghrelin displayed the most activity in their brain's pleasure centers when they saw images of edible items.

>> PLEASURE

Song of the Mouse

The noises mice make give clues about pleasure and emotions in the brain

The squeak of a mouse tells most people to buy a mousetrap, but it tells some researchers a lot more. According to a new study, mouse noises indicate certain states of mind, and monitoring their sounds can help scientists learn more about emotion, reward seeking and communication.

In addition to audible squeaks, mice produce ultrasonic noises—squeaks so high that humans cannot hear them. Males sing a complex song during sex and squeak when they are tickled, females chirp when around other females, and mouse pups squeak when their mothers abandon them. These vocalizations transform as the situation changes, too—male mice squeak more frequently as they get closer to ejaculation, and female mice make a ruckus when their female playmates have chocolate on their breath. Scientists at the University of Toronto, Northwestern University and the National Institutes of Health speculated that these noises and their intensities were linked to the activation of dopamine, a brain chemical involved in pleasure and reward seeking. They bred mice to lack certain aspects of dopamine function and monitored the resulting din. Sure enough, the dopamine-deprived mice were quieter on all counts, suggesting that mouse squeaks relate both to the experience of pleasure and to the desire for it.

The specially bred mice can teach scientists much about both mouse behavior and the human brain. "Because mouse genes are so similar to many human genes, it gives you a way of studying the genes for complex behaviors," says John Yeomans, a psychologist at the University of Toronto and the lead researcher of the study. Labs are already starting to use mouse noises to study language development, social bonding and diseases that have symptoms related to communication, including schizophrenia and autism. *—Melinda Wenner*

Optical illusions may fool the brain because it is trying to predict the future.

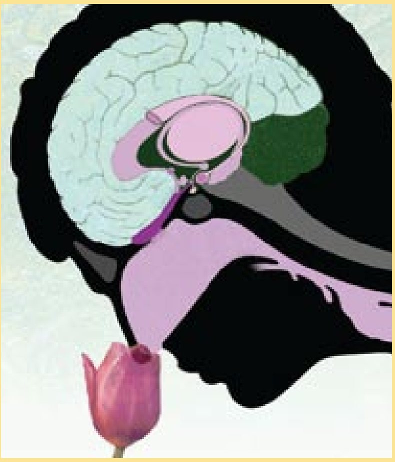
>> ILLUSION

Motion Magic

The brain looks forward

The brain takes nearly one tenth of a second to consciously register a scene. But the scenery changes far more quickly than that when we move. How does our brain cope? By constantly predicting the future, posits Mark Changizi, now at the Rensselaer Polytechnic Institute. This ability explains many visual illusions—look here, for example, as you move this page toward and away from you. The extra motion results from your brain estimating where the ellipses will be in several milliseconds, Changizi says. He and his colleagues explain this illusion and 50 others in April's *Cognitive Science.*
—Lucas Laursen

DAVID AUBREY *SPL/Photo Researchers, Inc. (top)*; MARK CHANGIZI *Rensselaer Polytechnic Institute (bottom)*



>> NEUROBIOLOGY

Smell Similarity

A new map untangles the complexities of comparing odor molecules

It is easy to see that red is closer to pink than to blue, but odors are harder to compare: Do almonds smell more like roses or bananas? According to a new "smell map" created by researchers at the Weizmann Institute of Science in Israel, almonds smell like roses—and the two scents elicit similar neural activity.

Led by neurobiologist Rafi Haddad, the team identified 40 defining characteristics for odors, such as molecular shape and structure, then translated the resulting profiles of 450 scents into locations on a multidimensional map. In the same way that similar colors are closer together on a rainbow, similar smells are located near one another in the 32-dimensional mathematical model. A scent's location on the map also predicts the brain activity caused by getting a whiff: previous research in a variety of animals such as fruit flies, honeybees, mice, rats and tadpoles showed that neighboring odors cause similar patterns of neuron activity. Based on these patterns, the researchers were able to accurately predict the neural signature of formerly untested scents.

The findings could help illuminate the laws that underlie our sense of smell, which are largely unknown and difficult to study, according to Haddad. The smell map might also aid in the study and prediction of animal behavior by illuminating which scents an animal considers good or bad. [For more on our sense of smell, see page 38.] *—Susan Cosier*

>> AGING

Talk to Teens, Live Longer

Aided by a gene, the young improve the health of the elderly

"Youth is a wonderful thing," George Bernard Shaw once said. "What a crime to waste it on children." Humor aside, recent research suggests that youthful energy may not be "wasted" after all. Through social interactions alone, the young can pass some of their vigor on to the elderly, improving the older generation's cognitive abilities and vascular health and even increasing their life span.

Although researchers have documented these benefits in mammals, such as rats, guinea pigs and nonhuman primates, the reason for the effect has remained unclear. Now biologist Chun-Fang Wu of the University of Iowa offers a genetic explanation. Wu and graduate student Hongyu Ruan found that the presence of youthful, active fruit flies doubled the life span of a group of flies with a mutation in *Sod1,* a gene that has been linked in humans to Alzheimer's disease and amyotrophic lateral sclerosis (ALS), a motor-neuron disorder also known as Lou Gehrig's disease.

Fruit flies are quite social, Wu explains; social cues govern both their reproduction and aging process. And their genes are easier to manipulate than those of their mammalian counterparts—by altering *Sod1,* Wu created flies that died after only about two weeks, a quarter of their normal life span. When housed with younger flies, however, the *Sod1* mutants lived for about 30 days. The mutant flies also became more physically fit, according to heat-stress tests and other measures, when housed with the younger "helpers." Clipping the younger flies' wings significantly reduced the positive effects on the mutants' life span, suggesting that physical activity plays a key role in the life-extending mechanism.

Physical activity is well known to benefit elderly humans, but working out in a social setting with younger people seems to be especially valuable. Sharon Arkin, a psychiatrist at the University of Arizona, runs a clinical program in which Alzheimer's patients engage in communal exercise sessions with college students. She showed that her program stabilizes cognitive decline and improves patients' moods.

So could the *Sod1* gene be playing a part in humans? Wu thinks it is possible. Besides the gene's association with Alzheimer's, Wu found that flies with the *Sod1* mutation were more receptive to social cues than flies with other age-accelerating mutations were. Further studies are needed to determine the therapeutic potential of intergenerational socialization—but visiting the grandparents probably couldn't hurt. *—Erica Westly*

HANS-ULRICH OSSTERWALDER *Photo Researchers, Inc.* (*left*); GETTY IMAGES (*right*)

>> DEPRESSION

Down in the Dark

Rats shed light on seasonal affective disorder

The association between darkness and depression is well established. Now a new study reveals for the first time the profound changes that light deprivation causes in the brain.

Neuroscientists at the University of Pennsylvania kept rats in the dark for six weeks. The animals not only exhibited depressive behavior but also suffered damage in brain regions known to be underactive in humans during depression. The researchers observed neurons that produce norepinephrine, dopamine and serotonin—common neurotransmitters involved in emotion, pleasure and cognition—in the process of dying. This neuronal death, which was accompanied in some areas by compromised synaptic connections, may be the mechanism underlying the darkness-related blues of seasonal affective disorder.

Principal investigator Gary Aston-Jones, now at the Medical University of South Carolina, speculates that the dark-induced

effects stem from a disruption of the body's clock. "When the circadian system is not receiving normal light, that in turn might lead to changes in brain systems that regulate mood," he says.

Treating the rats with an antidepressant significantly ameliorated brain damage and depressive behaviors. "Our study provides a new animal system for antidepressant development. Many existing animal models depend on stress. Our model is a stress-free means of producing a depression. It might be particularly relevant to seasonal affective disorder, but we think that it is relevant to depression overall," Aston-Jones says. —*Lisa Conti*

Neuronal death may be the mechanism underlying seasonal affective disorder.

>> DECISIONS

Polling Places' Surprising Sway

Where you vote can affect how you cast your ballot

Psychologists have long known that situations can shape behavior—for example, when time pressure turns would-be Good Samaritans into callous passersby. More recently, studies have shown that even cues as subtle as a mild scent can trigger changes in participants' thoughts and actions. But can environmental signals influence important decisions in the real world? A new study of election voting suggests they can.

Investigators at the Stanford Graduate School of Business analyzed data from Arizona's 2000 general election, looking for a link between where voters cast their ballots and whether they backed a school-funding initiative. Those who voted in a school were more likely than other voters to favor raising the sales tax to fund education. Even after accounting for factors such as where voters lived, the difference was large enough to tip a close vote.

The researchers then confirmed with a controlled experiment that environmental cues were likely to have caused the effect: participants who were primed with images of churches proved less likely to support a stem cell initiative than were subjects who were shown more neutral images, such as office buildings.

This effect occurs only if voters might go either way on an issue, explains study co-author Jonah Berger, now a professor at the University of Pennsylvania. "Environmental cues aren't going to get people to do things they wouldn't do otherwise," Berger says. He suggests that as a first step toward avoiding the induced bias, election officials might try to pick "more innocuous multipurpose rooms" in the polling place to reduce, for example, the religious stimuli in a church setting. —*Marina Krakovsky*

TOLEDANO *Getty Images (top)*; RYAN AUSTIN *AP Photo (bottom)*

>> MATH

A Natural Log

Our innate understanding of numbers may be logarithmic rather than linear

People who do not have formal education tend to think of numbers in terms of ratios.

We humans seem to be born with a number line in our head. But a new study suggests it may look less like an evenly segmented ruler and more like a logarithmic slide rule on which the distance between two numbers represents their ratio (when divided) rather than their difference (when subtracted).

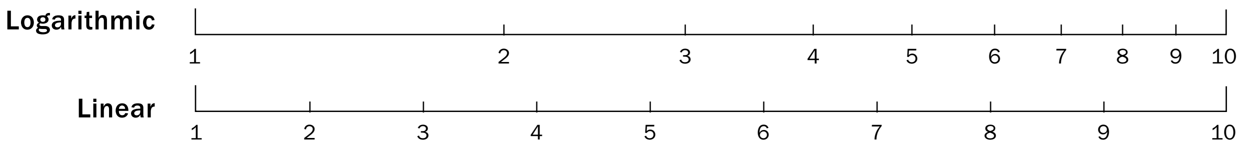
The mathematical idea of a number line—a line of numbers placed in order at equal intervals—is a simple yet surprisingly powerful tool, useful for everything from taking measurements to geometry and calculus.

Previous studies of Westerners showed that people tend to map numbers on a linear scale, with the numerals evenly spaced along the line. But if the numbers are presented as hard-to-count groups of dots, people will logarithmically group the larger numbers closer together on one end of the scale in what researchers call a "compression effect." Preschoolers also group numbers this way before they begin their formal education in math.

To investigate which number-line concept is innate, neuroscientist Stanislas Dehaene of the College of France in Paris worked with the Mundurukú, an Amazonian culture with little exposure to modern math or measuring devices. The Mundurukú were immediately able to place numbers on a line when asked, but they grouped them logarithmically.

Dehaene says the research suggests that a logarithmic number line might be an intuitive mathematical concept, whereas the idea of a linear number line might have to be learned.

—Kurt Kleiner



>> PERCEPTION

The Sound of Sight

A perceptual anomaly may help explain how the brain integrates sight and sound

In the peculiar neurological condition known as synesthesia, a person's senses meld together, so that a synesthete might "hear" colors or "taste" shapes. Now scientists have stumbled on a previously unknown form of synesthesia in which visual flashes or movements trigger perceptions of sound.

California Institute of Technology neuroscientists Melissa Saenz and Christof Koch confirmed the existence of hearing-motion synesthesia, as they dubbed it, by creating a task at which the synesthetes would have an advantage. The researchers presented four self-professed synesthetes and 10 nonsynesthetes with 100 pairs of Morse code–like rhythmic sequences, each composed of either auditory beeps or flashes of white on a black background. The participants judged whether the two sequences in each pair were the same or different.

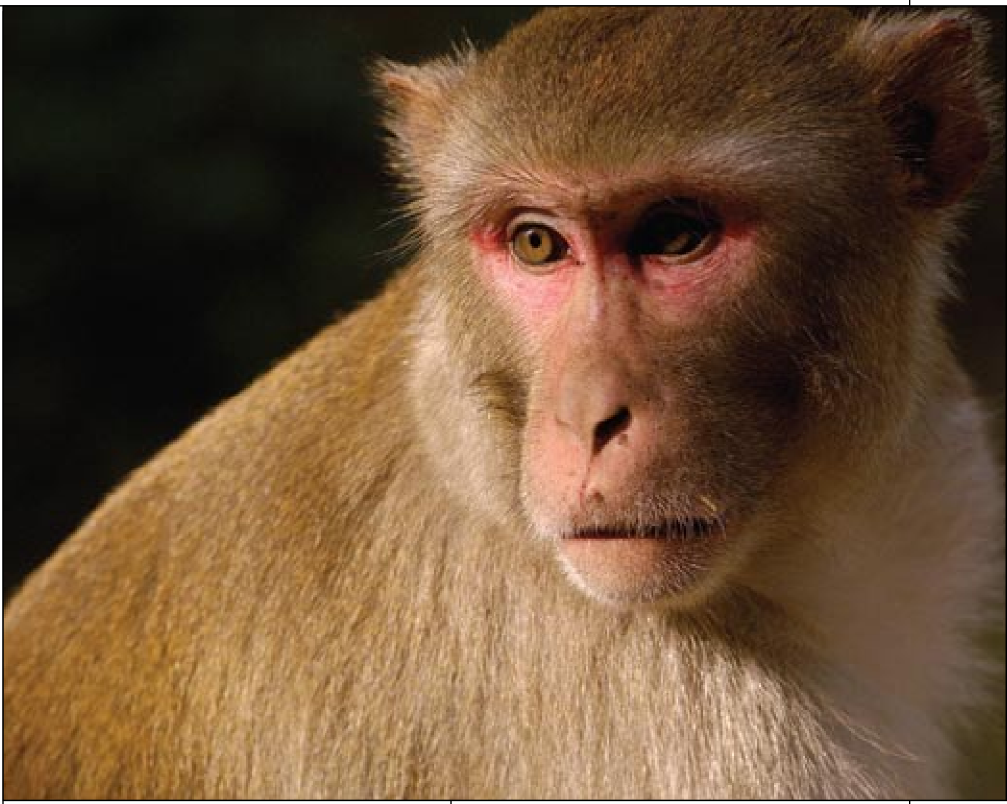
Both groups judged auditory patterns accurately about 85 percent of the time, the researchers found. On the visual trials, nonsynesthetes' judgments fell to nearly chance levels, a result that corroborates other research showing that most people are better at judging auditory patterns than assessing visual patterns. In contrast, synesthetes—who reported hearing sounds such as beeps or taps in time with the visual signals—distinguished matching from nonmatching rhythms 75 percent of the time.

"I think of these people as having an enhanced soundtrack in life," Saenz says. Her team is conducting brain-imaging studies to try to tease out the roots of that soundtrack as well as how a typical brain combines visual and auditory signals to improve perception. *—Siri Carpenter*

ART RAT *jupiterimages*

Monkeys Hear Voices

New research suggests that a brain area devoted to processing voices is not as uniquely human as had been previously assumed BY PASCAL BELIN



PETE OXFORD *Minden Pictures*

THE USE OF VOCALIZATIONS, such as grunts, songs or barks, is extremely common throughout the animal kingdom. Nevertheless, humans are the only species in which these vocalizations have attained the sophistication and communicative effectiveness of speech. How did our ancestors become the only speaking animals, some tens of thousands of years ago? Did this change happen abruptly, involving the sudden appearance of a new cerebral region or pattern of cerebral connections? Or did it happen through a more gradual evolutionary process, in which brain structures already present to some extent in other animals were put to a different and more complex use in the human brain?

A recent study in *Nature Neuroscience* yields critical new information, uncovering what could constitute the "missing link" between the brain of vocalizing nonhuman species and the human brain: evidence that a cerebral region specialized for processing voice, known to exist in the human brain, has a counterpart in the brain of rhesus macaques.

Neuroscientist Christopher I. Petkov of the Max Planck Institute for Biological Cybernetics in Tübingen, Germany, and his colleagues used functional magnetic resonance imaging to explore the macaque brain. They measured cerebral activity of awake monkeys that were listening to different categories of natural sounds, including macaque vocalizations. The researchers found evidence for a "voice area" in the auditory cortex of these macaques: a discrete region of the anterior temporal lobe in which activity was greater for macaque vocalizations than for other sound categories. This region was observed in several individuals, even under the condition of total anesthesia. More surprising, the region showed repetition-induced reduction of activity—or neuronal adaptation—in response to different calls coming from the same individual. This finding suggests that this brain region processes information about the identity of the speaker, a phenomenon that is also observed in the human voice area.

Long History of Voice?

Perhaps the most remarkable implication of these findings is that the voice area previously identified in the human brain is not uniquely human and that it has a counterpart in the brain of nonhuman primates. That discovery, in turn, implies that the voice area has a long evolutionary history and was probably already present in the common ancestor of macaques and humans some 20 million years ago. It is known that the cognitive talents underlying voice perception, such as speaker recognition, are shared with many other animal species, but the findings of Petkov and his colleagues provide a cerebral location for these abilities.

Ironically, most of the research into the evolutionary basis of language

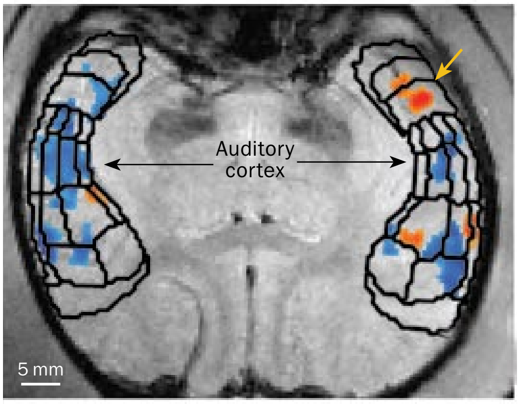
(The voice area has a **long evolutionary history** and was probably present some 20 million years ago.)

> Perhaps looking at **what we have in common** with other animals will help us understand the evolution of speech.

has focused so far on a single function—speech perception—which is unique to humans, and thus evolutionary precursors are hard, if not impossible, to identify. The present findings hint at another, possibly more rewarding, strategy: perhaps looking at what we have in common with other animals—that is, a rich cerebral substrate to process vocalizations and extract speaker-related information—will allow us to understand the evolution of speech. Indeed, Petkov's findings indicate that when our ancestors began to talk, they already were equipped with sophisticated neural machinery specialized in voice processing.

Another important implication of Petkov's findings concerns the functional lateralization of the macaque voice area. A well-established property of the human cerebral substrate for speech (particularly speech production) is its lateralization to the left hemisphere. This known asymmetry has led researchers to investigate whether a similar left-hemispheric bias could be found in other animals, as a possible evolutionary precursor of human language. Unfortunately, this long-standing belief has possibly resulted in a strong bias in the literature, whereby studies uncovering any leftward asymmetry in nonhuman primates are much more likely to be published in leading journals.

Speaker Recognition



A region (*yellow arrow*) in the right hemisphere of the macaque's auditory cortex responds more strongly to macaque vocalizations than to other natural sounds. Researchers believe that this "voice area," similar to the one in humans, processes information about the individual identities of other members of the species.

SOURCE: "A VOICE REGION IN THE MONKEY BRAIN," BY C. I. PETKOV ET AL., IN *NATURE NEUROSCIENCE*, VOL. 11, NO. 3; MARCH 2008

A Role for the Right

A counterintuitive but essential feature of Petkov's results, similar to the corresponding findings in the human brain, is that voice-selective activity was stronger in the right hemisphere. Furthermore, the identity-specific neuronal adaptation was observed only in the right hemisphere of the macaque brain, exactly as in the human studies. This finding means that the right hemisphere may well have played a major role in how speech appeared in our ancestors and that a response to the puzzle of speech evolution may lie not only in the left hemisphere.

We have much work ahead before we can attain a complete understanding of the functional role of the voice area, in macaques as well as in humans. Several alternative hypotheses remain to be tested: Does the voice area represent a hardwired preference for the particular acoustical structure of vocalizations from one's own species? Or is it more simply a "formant" detector, a structure specialized in detecting vocal features in general? Another possibility is that this voice area is actually a "social" structure, tuned to vocalizations because they are cues for social interaction and not because they share a particular acoustical structure.

In conclusion, Petkov's findings provide an exciting common substrate for high-level, or complex, auditory cognition that can be studied in parallel in humans and in macaques. Now that the location of the voice area in the macaque brain has been established, researchers will obtain critical additional information in the near future by exploring the monkey's voice area using more conventional electrophysiological techniques, such as recording directly from neurons. Even more important, this seminal work opens the road for comparative neuroimaging studies in which humans and other animals perform similar tasks using similar methodologies, and the results can be analyzed using similar strategies. **M**

PASCAL BELIN is a professor of psychology at the University of Glasgow.

(Further Reading)

- **Voice-Selective Areas in Human Auditory Cortex.** Pascal Belin, Robert J. Zatorre, Philippe Lafaille, Pierre Ahad and Bruce Pike in *Nature*, Vol. 403, pages 309–312; January 20, 2000.
- **Adaptation to Speaker's Voice in Right Anterior Temporal Lobe.** Pascal Belin and Robert J. Zatorre in *NeuroReport*, Vol. 14, No. 16, pages 2105–2109; November 14, 2003.
- **A Voice Region in the Monkey Brain.** Christopher I. Petkov, Christoph Kayser, Thomas Steudel, Kevin Whittingstall, Mark Augath and Nikos K. Logothetis in *Nature Neuroscience*, Vol. 11, No. 3, pages 367–374; March 2008.

Seeing Is Believing

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

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.

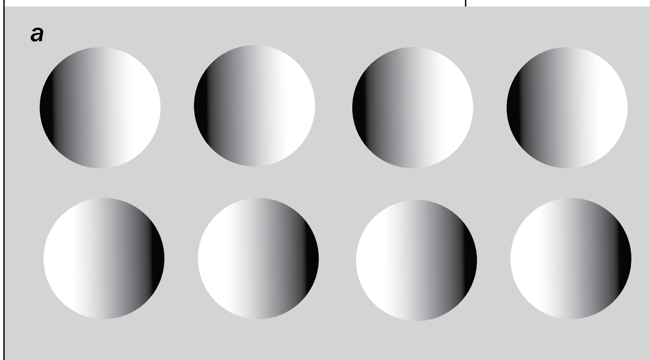
A dark back and light belly help this caterpillar avoid detection.

EMIL VON MALTITZ *Getty Images*

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.

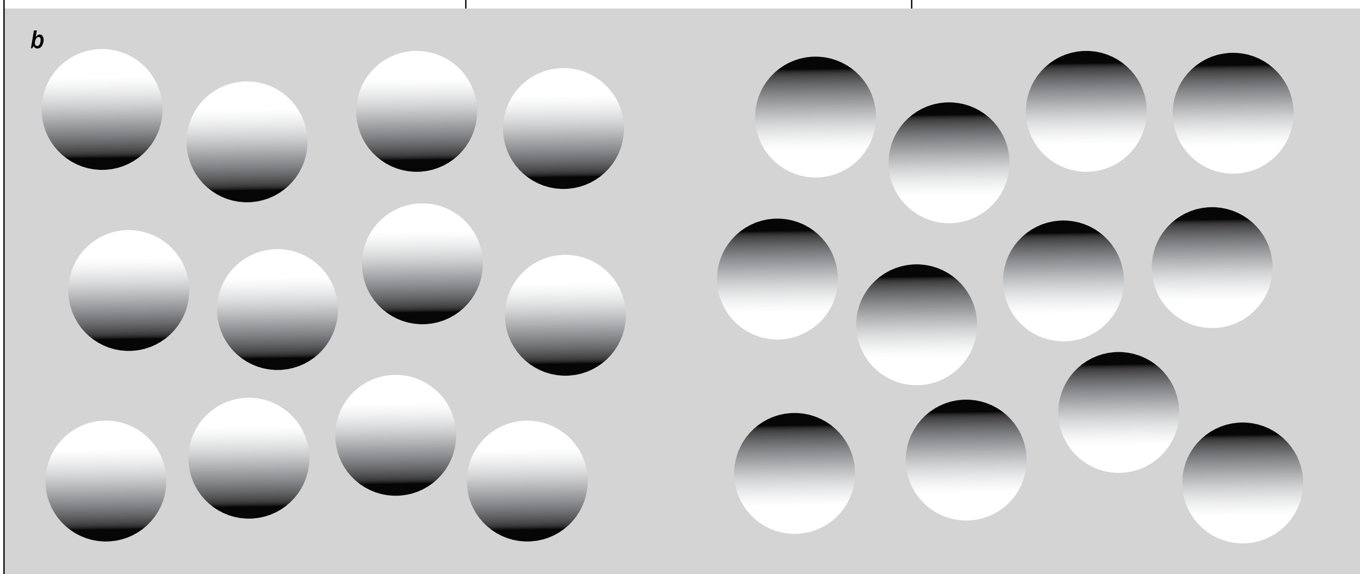
From this experiment we learn that despite the impression of seamless unity, vision is actually mediated by multiple parallel information-processing modules in the brain. Some of the modules connect to the vestibular system; however, the one that handles shape from shading does not. The reason might 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

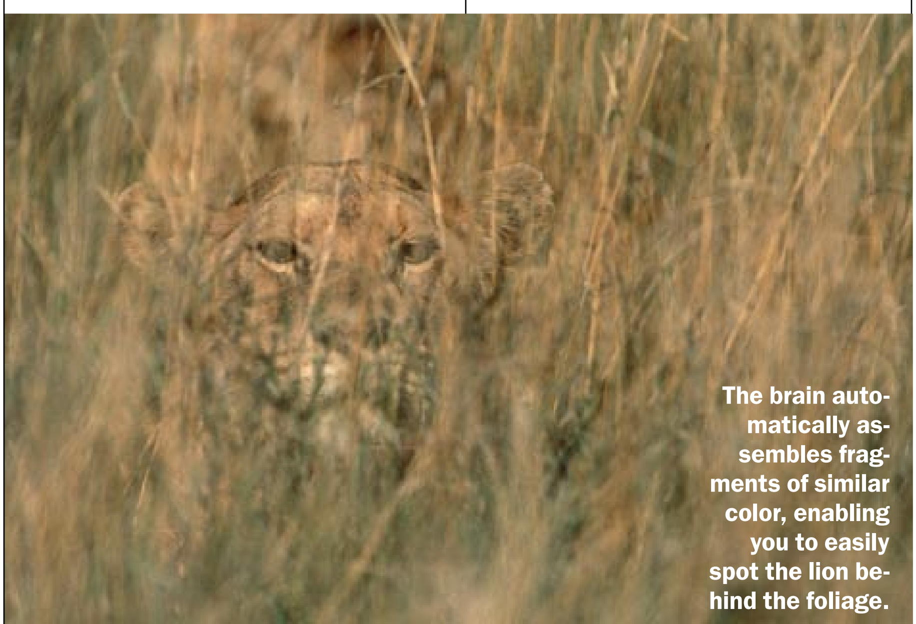
> Over millions of years, **evolution has "discovered"** and taken advantage of the principles of shading that researchers have explored only lately.



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





The brain automatically assembles fragments of similar color, enabling you to easily spot the lion behind the foliage.

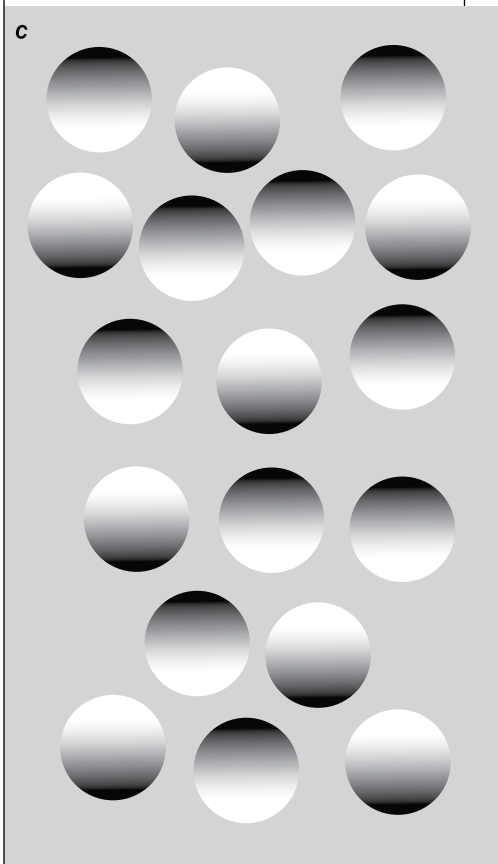
primitive feature that is extracted early, whereas a smile is not.

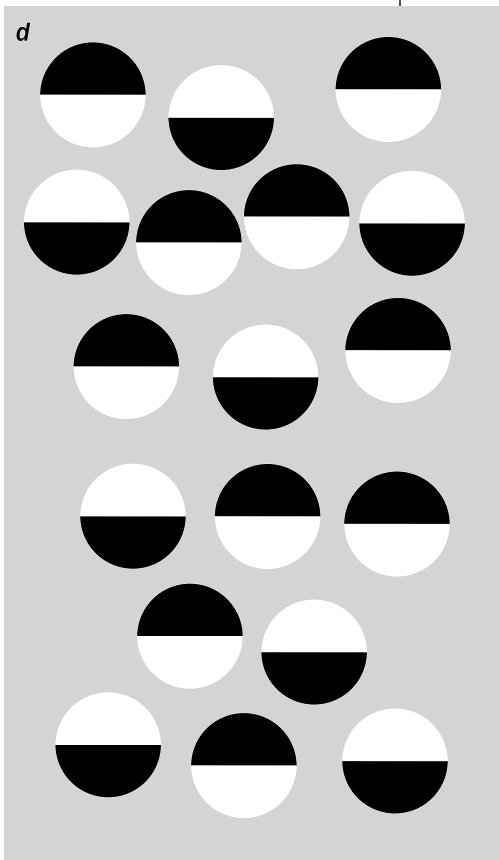
(It makes survival sense to be able to piece together fragments of similar color. A lion hidden behind a screen of green leaves is visible merely as gold fragments, but the visual brain assembles the pieces into a single, gold, lion-shaped form and warns: "Get out of here!" On the other hand, objects 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. 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

NADIA STRASSER (*illustrations*); MITSUAKI IWAGO *Minden Pictures* (*photograph*)

> (Despite the impression of seamless unity, vision is actually mediated by **multiple modules in the brain**.)





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 birds' courtship display, however, the tail feathers become erect. In this position, the spots are paler on top and duskier 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. **M**

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, and serve as members of the board of advisors for *Scientific American Mind*. Ramachandran is author of *A Brief Tour of Human Consciousness: From Impostor Poodles to Purple Numbers* (Pi Press, 2005). Rogers-Ramachandran was a researcher at the University of North Carolina at Chapel Hill before moving to U.C.S.D. This column is reprinted from an earlier issue of *Scientific American Mind*.

(Further Reading)

- **Perceiving Shape from Shading.** Vilayanur S. Ramachandran in *Scientific American,* Vol. 259, No. 2, pages 76–83; August 1988.
- **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.

NADIA STRASSER

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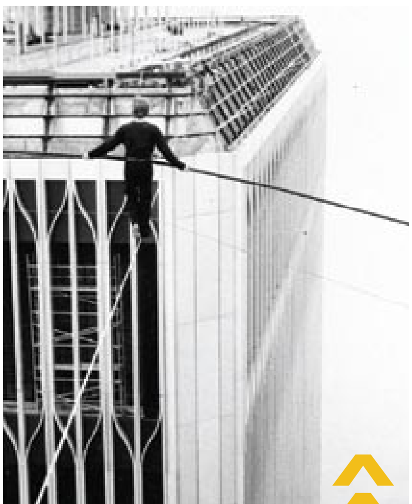
(calendar)

August

14–17 Join more than 10,000 psychologists and brain scientists at the **American Psychological Association's 116th Annual Convention**. Discuss the latest research in intelligence, emotions and mental health or just sit back and listen to the impressive lineup of speakers. This year's keynote address will come from Malcolm Gladwell, *New Yorker* staff writer and best-selling author of *The Tipping Point* (Back Bay Books, 2002) and *Blink* (Little, Brown, 2005).
Boston
www.apa.org/convention08



15 What drives some people to break the law and even endanger their lives for the sake of their art? The new documentary ***Man on Wire*** delves into the mind of the man who perpetrated what some consider to be the "artistic crime of the century." In 1974 a tightrope walker named Philippe Petit performed a high-wire routine between the two towers of the World Trade Center for nearly an hour before the New York City police department managed to coax him down. The film celebrates and explores what makes such free spirits tick.
Magnolia Pictures and Discovery Films
www.manonwire.com

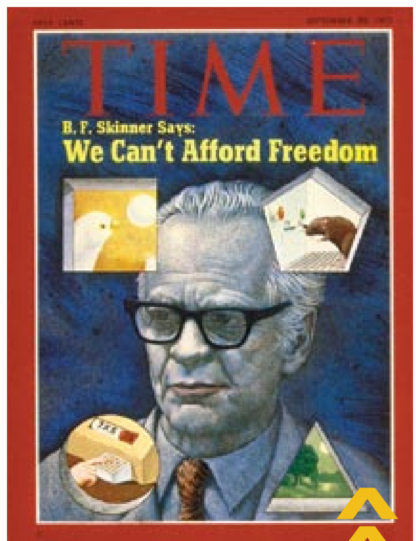
September

6–11 Tired of opening these pages and reading about *other* people's brains? Then don't miss this chance to donate your own neural experiences to science. The British Association for the Advancement of Science and psychologists at the University of Leeds need your "Help!" on their **Magical Memory Tour**, a study of the link between music and memory. By asking people around the world to share the vivid associations they have with particular Beatles songs, the researchers hope to learn how music—with its strong recollective power—helps to shape personal histories. The results of this mass-participation survey will be launched at the association's Festival of Science September 6–11.
Liverpool, England
www.magicalmemorytour.com

8–13 As the Games of the XXIX Olympiad are wrapping up in China, Russia will be hosting its own **Olympics of the Brain**. For its 14th annual conference, the International Organization of Psychophysiology invites attendees to the birthplace of the field. In the late 19th century, Russian neuroscientists and physiologists paved the way for a branch of psychology uniquely concerned with the relations among mind, body and behavior. Lecturers will discuss the neural and autonomic responses that accompany our emotions and cognitive processes, including aggression, anxiety, creativity and consciousness, and address questions such as "What makes humans humane?"
St. Petersburg, Russia
www.world-psychophysiology.org

14 The most iconic psychophysiologist, **Ivan Petrovich Pavlov**, was born in Ryazan, Russia, on this date in 1849. His experimental research on the physiology of digestion won him the 1904 Nobel Prize in Physiology or Medicine, and it also led him to first describe the phenomenon of classical conditioning, the research for which he is most famous. While studying canine gastric functions, he noticed that his dogs began to salivate long before receiving any food. Pavlov ultimately showed that this conditioned reflex originated in the cerebral cortex. His study of the link between an animal's previous experience and its brain-mediated "Pavlovian response" exemplified a new trend in scientific investigation of the complex relations between whole organisms and their environment.

19 Being able to see is a skill most of us take for granted. It is hard enough to imagine the emotional and psychological turmoil that would accompany losing our eyesight, but what if *everyone* was suddenly unable to see? The new suspense drama ***Blindness***, based on José Saramago's 1995 novel of the same name, examines the rapid breakdown of social order after the entire population loses this most crucial sense. Julianne Moore stars.
Miramax
www.blindness-themovie.com



20 On this day in 1971 the influential psychologist **B. F. Skinner** appeared on the cover of *Time* magazine, which proclaimed, "B. F. Skinner Says: We Can't Afford Freedom." The story, along with Skinner's concurrently released book, *Beyond Freedom and Dignity* (Knopf), expounded his theory that free will is an illusion—human behavior is nothing more than a product of biology and environmental stimuli. To Skinner's surprise, the article was met with outrage as people took offense to what they saw as an attack on American ideology. Despite the controversy, his ideas paved the way for years of important research.

ALAN WELNER *AP Photo (tightrope)*; TIME & LIFE PICTURES/GETTY IMAGES *(Time cover)*

Compiled by Rachel Dvoskin and Karen Schrock. Send items to editors@SciAmMind.com

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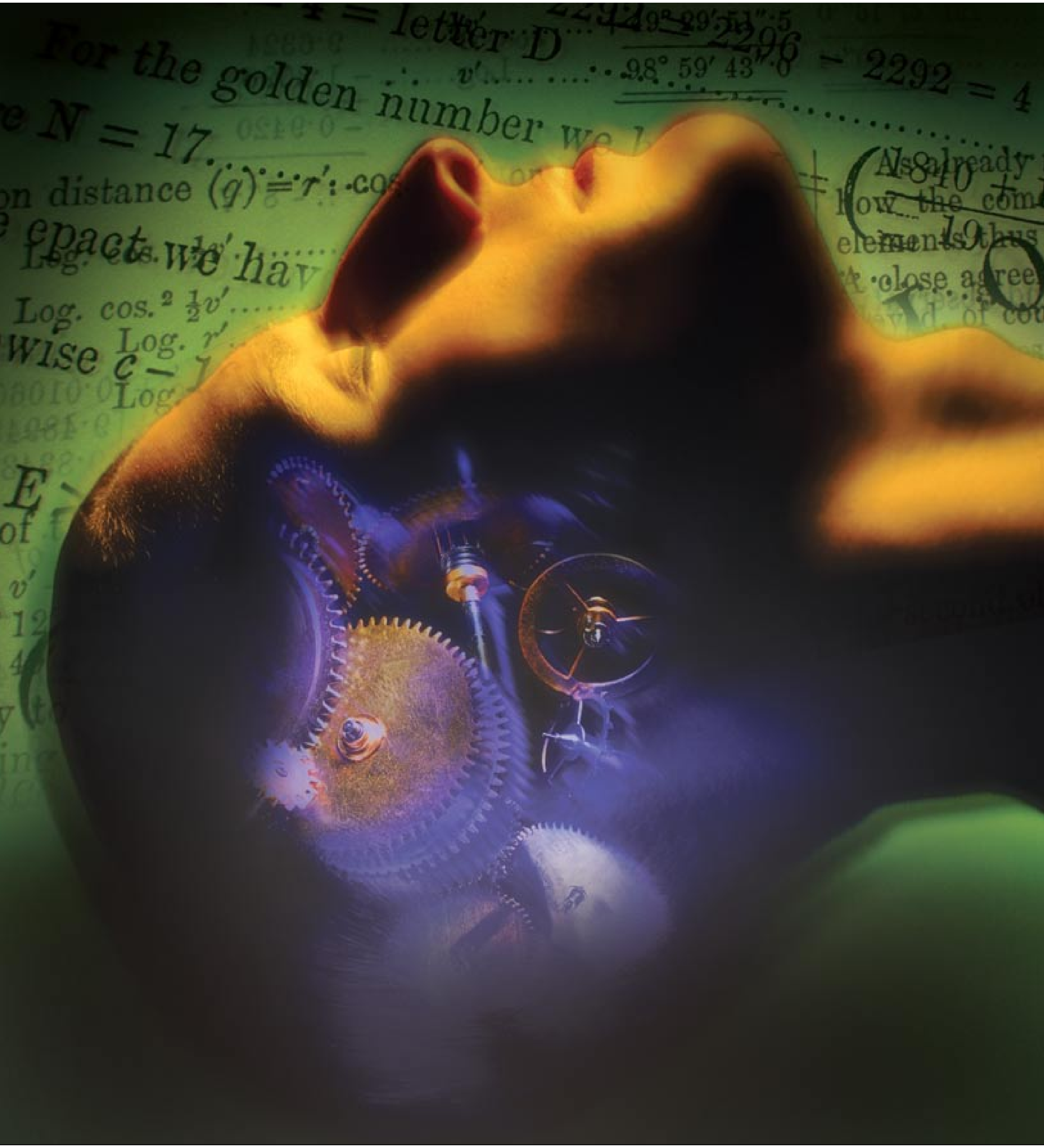
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Quiet! Sleeping Brain at Work

During slumber, our brain engages in data analysis, from strengthening memories to solving problems

By Robert Stickgold and Jeffrey M. Ellenbogen

In 1865 Friedrich August Kekulé woke up from a strange dream: he imagined a snake forming a circle and biting its own tail. Like many organic chemists of the time, Kekulé had been working feverishly to describe the true chemical structure of benzene, a problem that continually eluded understanding. But Kekulé's dream of a snake swallowing its tail, so the story goes, helped him to accurately realize that benzene's structure formed a ring. This insight paved the way for a new understanding of organic chemistry and earned Kekulé a title of nobility in Germany.

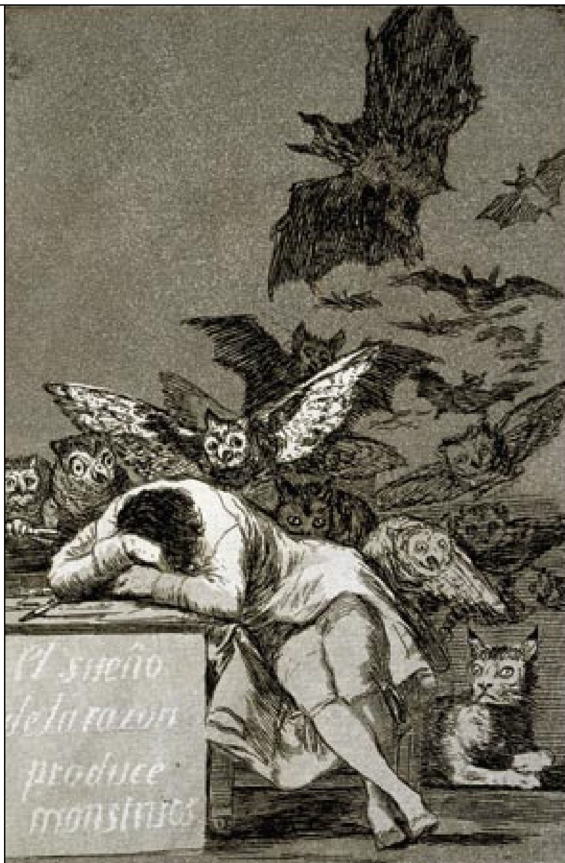
Although most of us have not been ennobled, there is something undeniably familiar about Kekulé's problem-solving method. Whether deciding to go to a particular college, accept a challenging job offer or propose to a future spouse, "sleeping on it" seems to provide the clarity we need to piece together life's puzzles. But how does slumber present us with answers?

The latest research suggests that while we are peacefully asleep our brain is busily processing the day's information. It combs through recently formed memories, stabilizing, copying and filing them, so that they will be more useful the next day. A night of sleep can make memories resistant to interference from other information and allow us to recall them for use more effectively the next morning. And sleep not only strengthens memories, it also lets the brain sift through newly formed memories, possibly even identifying what is worth keeping and selectively maintaining or enhancing these aspects of a memory. When a picture contains both emotional and unemotional elements, sleep can save the important emotional parts and let the less relevant background drift away. It can analyze collections of memories to discover relations among them or identify the gist of a memory while the unnecessary details fade—perhaps even helping us find the *meaning* in what we have learned.

Not Merely Resting

If you find this news surprising, you are not alone. Until the mid-1950s, scientists generally assumed that the brain was shut down while we snoozed. Although German psychologist Hermann Ebbinghaus had evidence in 1885 that

RICK GAYLE Corbis (head and gears); GETTY IMAGES (background)



The mystery of what happens during sleep has provoked many theories over the centuries.

THE SLEEP OF REASON PRODUCES MONSTERS, BY FRANCISCO GOYA, © BRITISH MUSEUM/ART RESOURCE, NY

sleep protects simple memories from decay, for decades researchers attributed the effect to a passive protection against interference. We forget things, they argued, because all the new information coming in pushes out the existing memories. But because there is nothing coming in while we get shut-eye, we simply do not forget as much.

Then, in 1953, the late physiologists Eugene Aserinsky and Nathaniel Kleitman of the University of Chicago discovered the rich variations in brain activity during sleep, and scientists realized they had been missing something important. Aserinsky and Kleitman found that our sleep follows a 90-minute cycle, in and out of rapid-eye-movement (REM) sleep. During REM sleep, our brain waves—the oscillating electromagnetic signals that result from large-scale brain activity—look similar to those produced while we are awake [*see illustration on opposite page*]. And in subsequent decades, the late Mircea Steriade of Laval University in Quebec and other neuroscientists discovered that individual collections of neurons were independently firing in between these REM phases, during periods known as slow-wave sleep, when large populations of brain cells fire synchronously in a steady rhythm of one to four beats each second. So it became clear that the sleeping brain was not merely "resting," either in REM sleep or in slow-wave sleep. Sleep was doing something different. Something *active*.

Sleep to Remember

The turning point in our understanding of sleep and memory came in 1994 in a groundbreaking study. Neurobiologists Avi Karni, Dov Sagi and their colleagues at the Weizmann Institute of Science in Israel showed that when volunteers got a night of sleep, they improved at a task that involved rapidly discriminating between objects they saw—but only when they had had normal amounts of REM sleep. When the subjects were deprived of REM sleep, the improvement disappeared. The fact that performance actually rose overnight negated the idea of passive protection. Something had to be happening within the sleeping brain that altered the memories formed the day before. But Karni and Sagi described REM sleep as a permissive state—one that *could* allow changes to happen—rather than a necessary one. They proposed that such unconscious improvements could happen across the day or the night. What was important, they argued, was that improvements could only occur during *part* of the night, during REM.

It was not until one of us (Stickgold) revisited this question in 2000 that it became clear that sleep could, in fact, be necessary for this improvement to occur. Using the same rapid visual discrimination task, we found that only with more than six hours of sleep did people's performance improve over the 24 hours following the learning session. And REM sleep was not the only important component: slow-wave sleep was equally crucial. In other words, sleep—in all its phases—does something to improve memory that being awake does not do.

To understand how that could be so, it helps to review a few memory basics. When we "en-

FAST FACTS

While We Are Sleeping

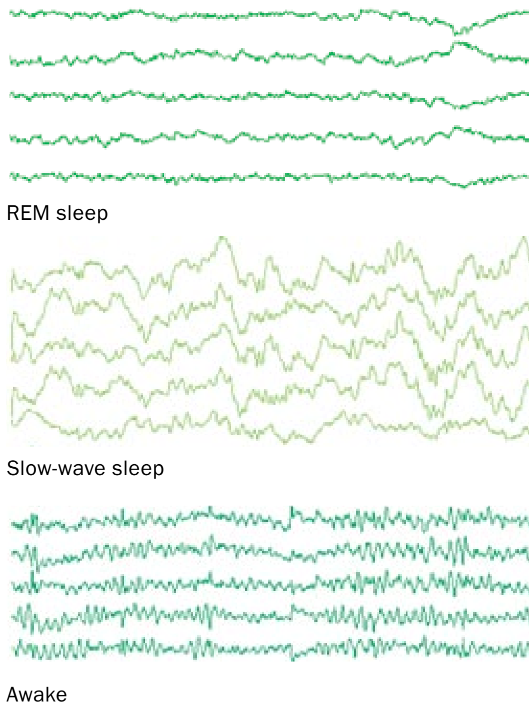
1» As we snooze, our brain is busily processing the information we have learned during the day.

2» Sleep makes memories stronger, and it even appears to weed out irrelevant details and background information so that only the important pieces remain.

3» Our brain also works during slumber to find hidden relations among memories and to solve problems we were working on while awake.

code" information in our brain, the newly minted memory is actually just beginning a long journey during which it will be stabilized, enhanced and qualitatively altered, until it bears only faint resemblance to its original form. Over the first few hours, a memory can become more stable, resistant to interference from competing memories. But over longer periods, the brain seems to decide what is important to remember and what is not—and a detailed memory evolves into something more like a story.

In 2006 we demonstrated the powerful ability of sleep to stabilize memories and provided further evidence against the myth that sleep only passively (and, therefore, transiently) protects memories from interference. We reasoned that if sleep merely provides a transient benefit for memory, then memories after sleep should be, once again, susceptible to interference. We first trained people to memorize pairs of words in an A-B pattern (for example, "blanket-window") and then allowed some of the volunteers to sleep.



The discovery in 1953 of rapid-eye-movement sleep and its characteristic brain activity (*top*), detected with electroencephalography, dispelled the notion that the brain simply rests during sleep. Soon after, slow-wave sleep patterns (*middle*) were discovered.

COURTESY OF JEFFREY M. ELLENBOGEN

(Sleep, it seems, does something to **improve memory** that being awake does not do.)

Later they all learned pairs in an A-C pattern ("blanket-sneaker"), which were meant to interfere with their memories of the A-B pairs. As expected, the people who slept could remember more of the A-B pairs than people who had stayed awake could. And when we introduced interfering A-C pairs, it was even more apparent that those who slept had a stronger, more stable memory for the A-B sets. Sleep changed the memory, making it robust and more resistant to interference in the coming day.

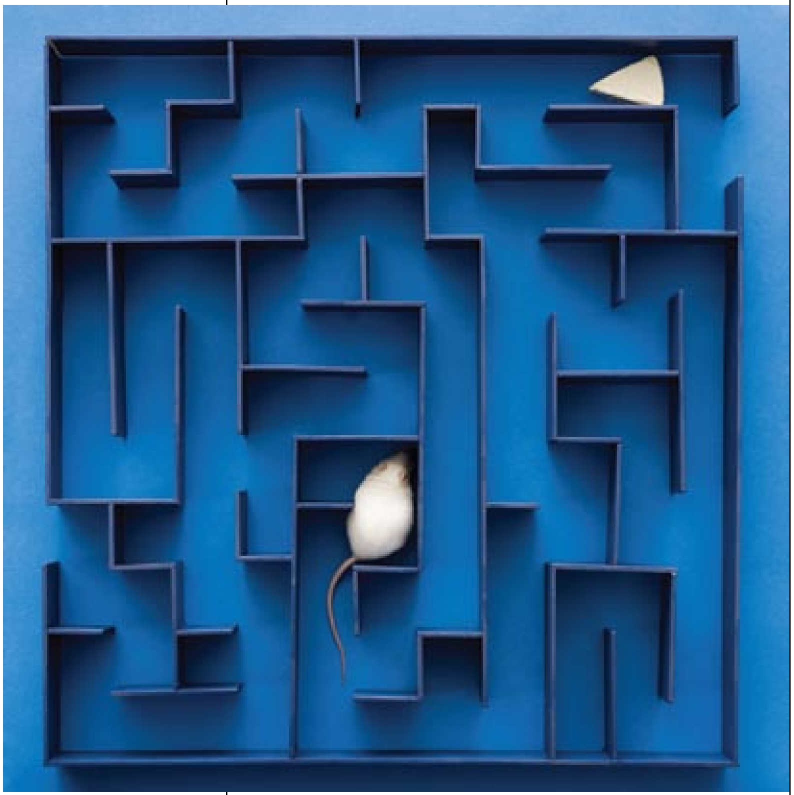
But sleep's effects on memory are not limited to stabilization. Over just the past few years, a number of studies have demonstrated the sophistication of the memory processing that happens during slumber. In fact, it appears that as we sleep, the brain might even be dissecting our memories and retaining only the most salient details. In one study we created a series of pictures that included either unpleasant or neutral objects on a neutral background and then had people view the pictures one after another. Twelve hours later we tested their memories for the objects and the backgrounds. The results were quite surprising. Whether the subjects had stayed awake or slept, the accuracy of their memories dropped by 10 percent for everything. Everything, that is, except for the memory of the emotionally evocative objects after a night of sleep. Instead of deteriorating, memories for the emotional objects actually seemed to improve by a few percent overnight, showing about a 15 percent improvement relative to the deteriorating backgrounds. After a few more nights, one could imagine that little but the emotional objects would be left. We know this culling happens over time with real-life events, but now it appears that sleep may play a crucial role in this evolution of emotional memories.

Precisely how the brain strengthens and enhances memories remains largely a mystery, although we can make some educated guesses at the basic mechanism. We know that memories are created by altering the strengths of connections among hundreds, thousands or perhaps even millions of neurons, making certain *patterns* of activity more likely to recur. These patterns of activity, when reactivated, lead to the recall of a memory—whether that memory is where we left the car keys or a pair of words such as "blanket-window." These changes in synaptic strength are thought to arise from a molecular

(The sleeping brain may be **selectively rehearsing** the more difficult aspects of a new task.)

process known as long-term potentiation, which strengthens the connections between pairs of neurons that fire at the same time. Thus, cells that fire together wire together, locking the pattern in place for future recall.

During sleep, the brain reactivates patterns of neural activity that it performed during the day, thus strengthening the memories by long-term potentiation. In 1994 neuroscientists Matthew Wilson and Bruce McNaughton, both then at the University of Arizona, showed this effect for the first time using rats fitted with implants that monitored their brain activity. They taught these rats to circle a track to find food, recording neuronal firing patterns from the rodents' brains all the while. Cells in the hippocampus—a brain structure critical for spatial memory—created a map of the track, with different "place cells" firing as the rats traversed each region of the track [see "The Matrix in Your Head," by James J. Knierim; Scientific American Mind, June/July 2007]. Place cells correspond so closely to exact physical locations that the researchers could monitor the rats' progress around the track simply by watching which place cells were firing at any given time. And here is where it gets even more interesting: when Wilson and McNaughton continued to record from these place cells as the rats slept, they saw the cells continuing to fire in the same order—as if the rats were "practicing" running around the track in their sleep.



When a rat runs a maze, neurons in its brain called place cells are active as it traverses specific regions of the track. Later, as the rat sleeps, the same neurons fire—the rat rehearses its run of the maze while unconscious.

AGE FOTOSTOCK

As this unconscious rehearsing strengthens memory, something more complex is happening as well—the brain may be selectively rehearsing the more difficult aspects of a task. For instance, Matthew P. Walker's work at Harvard Medical School in 2005 demonstrated that when subjects learned to type complicated sequences such as 4-1-3-2-4 on a keyboard (much like learning a new piano score), sleeping between practice sessions led to faster and more coordinated finger movements. But on more careful examination, he found that people were not simply getting faster overall on this typing task. Instead each subject was getting faster on those particular keystroke sequences at which he or she was worst.

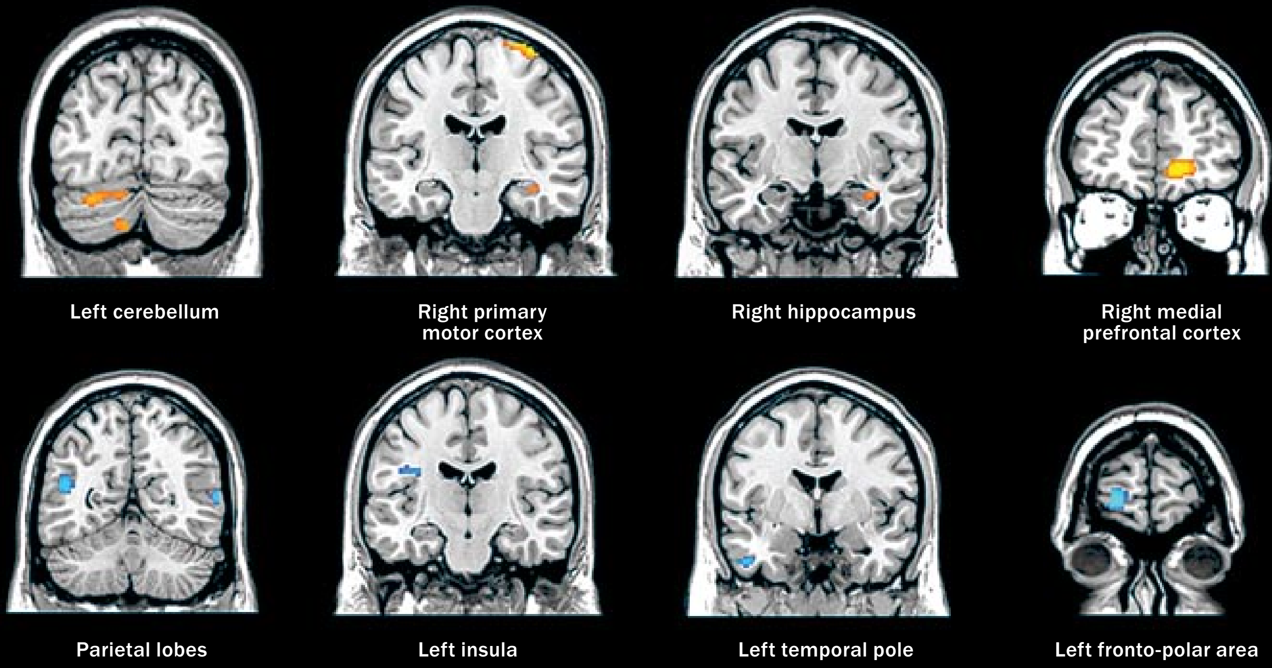
The brain accomplishes this improvement, at least in part, by moving the memory for these sequences overnight. Using functional magnetic resonance imaging, Walker showed that his subjects used different brain regions to control their typing after they had slept [*see box on opposite page*]. The next day typing elicited more activity in the right primary motor cortex, medial prefrontal lobe, hippocampus and left cerebellum—places that would support faster and more precise key-press movements—and less activity in the parietal cortices, left insula, temporal pole and frontopolar region, areas whose suppression indicates reduced conscious and emotional effort. The entire memory got strengthened, but especially the parts that needed it most, and sleep was doing this work by using different parts of the brain than were used while learning the task.

Solutions in the Dark

These effects of sleep on memory are impressive. Adding to the excitement, recent discoveries show that sleep also facilitates the active analysis of new memories, enabling the brain to solve problems and infer new information. In 2007 one of us (Ellenbogen) showed that the brain learns while we are asleep. The study used a transitive inference task; for example, if Bill is older

Nocturnal Practice

When pianists learn a new score, they practice difficult runs again and again until the motions become second nature. Part of this internalizing process depends on sleep: a 2005 functional MRI study showed that when people snooze after they learn to type complicated sequences, different brain regions become involved in controlling the keystrokes.



The brain regions indicated in yellow were more active during practice sessions after a night of sleep. These areas support faster typing and more precise keyboard movements—and indeed, subjects who slept improved their speed and accuracy more than did subjects who remained awake between rehearsals. The areas highlighted in blue were less active after sleep, indicating a reduction in conscious and emotional effort during the typing task.

COURTESY OF MATTHEW P. WALKER *University of California, Berkeley*

than Carol and Carol is older than Pierre, the laws of transitivity make it clear that Bill is older than Pierre. Making this inference requires stitching those two fragments of information together. People and animals tend to make these transitive inferences without much conscious thought, and the ability to do so serves as an enormously helpful cognitive skill: we discover new information (Bill is older than Pierre) without ever learning it directly.

The inference seems obvious in Bill and Pierre's case, but in the experiment, we used abstract colored shapes that have no intuitive relation to one another [*see top illustration on next page*], making the task more challenging. We taught people so-called premise pairs—they learned to choose, for example, the orange oval over the turquoise one, turquoise over green, green over paisley, and so on. The premise pairs imply a hierarchy—if orange is a better choice than turquoise and turquoise is preferred to green, then orange should win over green. But when we tested the subjects on these novel pairings 20 minutes after they learned the premise pairs, they had not yet discovered these hidden relations. They chose green just as often as they chose orange, performing no better than chance.

When we tested subjects 12 hours later on the same day, however, they made the correct choice 70 percent of the time. Simply allowing time to pass enabled the brain to calculate and learn these transitive inferences. And people who slept during the 12 hours performed significantly better, linking the most distant pairs (such as orange versus paisley) with 90 percent accuracy. So it seems the brain needs time after we learn information to process it, connecting

(The Authors)

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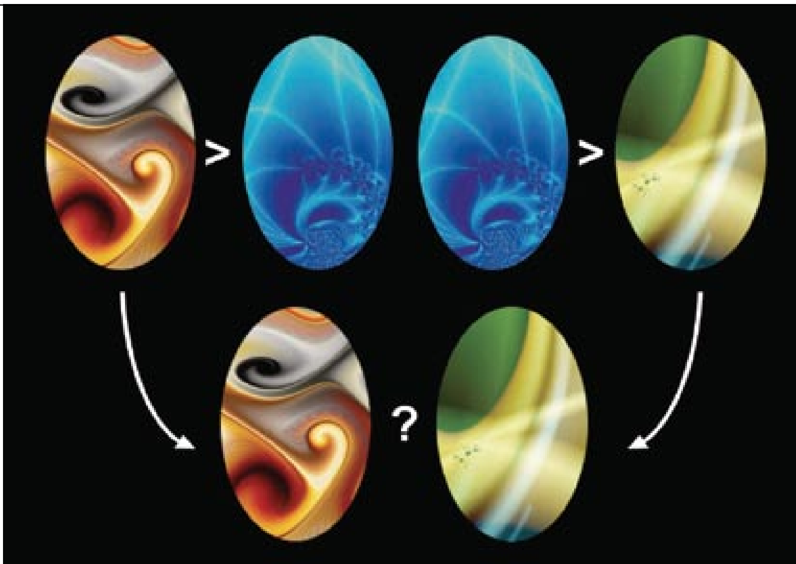


Through trial and error, study volunteers learned that orange is a better choice than turquoise, and turquoise is preferred to green. But only after time did they infer the hidden relation between orange and green, and with harder problems, sleep gave a distinct advantage.

the dots, so to speak—and sleep provides the maximum benefit.

In a 2004 study Ullrich Wagner and others in Jan Born's laboratory at the University of Lübeck in Germany elegantly demonstrated just how powerful sleep's processing of memories can be. They taught subjects how to solve a particular type of mathematical problem by using a long and tedious procedure and had them practice it about 100 times. The subjects were then sent away and told to come back 12 hours later, when they were instructed to try it another 200 times.

What the researchers had not told their subjects was that there is a much simpler way to solve these problems [*see box below*]. The researchers could tell if and when subjects gained insight into this shortcut, because their speed would suddenly increase. Many of the subjects did, in fact, discover the trick during the second session. But when they got a night's worth of sleep between the two sessions, they were more than two and a half times more likely to figure it out—59 percent of the subjects who slept found the trick, compared with only 23 percent of those who stayed awake between the sessions. Somehow the sleeping brain was solving this problem, without even knowing that there was a problem to solve.

The Need to Sleep

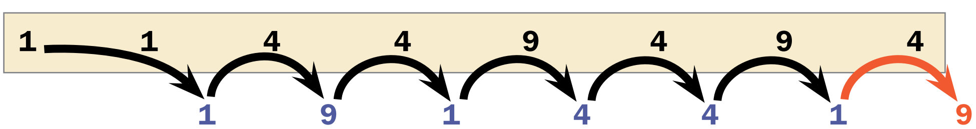
As exciting findings such as these come in more and more rapidly, we are becoming sure of one thing: while we sleep, our brain is anything but inactive. It is now clear that sleep can consolidate memories by enhancing and stabilizing them and by finding patterns within studied material even when we do not know that patterns might be there. It is also obvious that skimping on sleep stymies these crucial cognitive processes: some aspects of memory consolidation only happen with more than six hours of sleep. Miss a night, and the day's memories might be compromised—an unsettling thought in our fast-paced, sleep-deprived society.

But the question remains: Why did we evolve in such a way that certain cognitive functions happen only while we are asleep? Would it not seem to make more sense to have these operations going on in the daytime? Part of the answer might be that the evolutionary pressures for sleep existed long before higher cognition—functions such as immune system regulation and efficient energy usage (for instance, hunt in the day and rest at night) are only two of the many reasons it makes sense to sleep on a planet that alternates between light and darkness. And because we al-

Sudden Insight

Researchers taught subjects to use two rules to solve a type of problem that consists of a series of ones, fours and nines: Starting from the left, look at the first two numbers. If they are the same, write this number down (*shown here in blue*). If they are different, write down the third possible number (for example, if they are a 1 and a 4, write down 9). Then take this intermediate (*blue*) number and the next (*black*) number, and do it again. When you enter the final answer (*the red 9 here*), press the "Enter" key to tell the computer you're done.

What the subjects were not told is that the second-to-last unique number in the original series (*the black 9 just before the final 4 in this case*) will always be equivalent to the answer of the problem. After sleeping, most of the volunteers figured out the trick. *—R.S. and J.M.E.*



JEFFREY M. ELLENBOGEN (*top*)

(The brain evolved to use **light and darkness** wisely: acquire information by day; process it by night.)

We may be able to get by on as little as six hours of sleep a night, but closer to eight hours is better—and may optimize learning and memory performance.

JUPITERIMAGES

ready had evolutionary pressure to sleep, the theory goes, the brain evolved to use that time wisely by processing information from the previous day: acquire by day; process by night.

Or it might have been the other way around. Memory processing seems to be the only function of sleep that actually requires an organism to truly sleep—that is, to become unaware of its surroundings and stop processing incoming sensory signals. This unconscious cognition appears to demand the same brain resources used for processing incoming signals when awake. The brain, therefore, might have to shut off external inputs to get this job done. In contrast, although other functions such as immune system regulation might be more readily performed when an organism is inactive, there does not seem to be any reason why the organism would need to lose awareness. Thus, it may be these other functions that have been added to take advantage of the sleep that had already evolved for memory.

Many other questions remain about our nighttime cognition, however it might have evolved. Exactly how does the brain accomplish this memory processing? What are the chemical or molecular activities that account for these effects? These questions raise a larger issue about memory in general: What makes the brain remember certain pieces of information and forget others? We think the lesson here is that understanding sleep will ultimately help us to better understand memory.

The task might seem daunting, but these puzzles are the kind on which scientists thrive—and they can be answered. First, we will have to design and carry out more and more experiments, slowly teasing out answers. But equally important, we are going to have to sleep on it. M

(Further Reading)

- **Visual Discrimination Learning Requires Sleep after Training.** Robert Stickgold, LaTanya James and J. Allan Hobson in *Nature Neuroscience,* Vol. 3, No. 12, pages 1237–1238; December 2000.
- **Sleep Inspires Insight.** Ullrich Wagner, Steffen Gais, Hilde Haider, Rolf Verleger and Jan Born in *Nature,* Vol. 427, pages 352–355; January 22, 2004.
- **Sleep-Dependent Memory Consolidation.** Robert Stickgold in *Nature,* Vol. 437, pages 1272–1278; October 27, 2005.
- **Coordinated Memory Replay in the Visual Cortex and Hippocampus during Sleep.** Daoyun Ji and Matthew Wilson in *Nature Neuroscience,* Vol. 10, No. 1; January 2007.
- **Human Relational Memory Requires Time and Sleep.** J. M. Ellenbogen, P. Hu, J. D. Payne, D. Titone and M. P. Walker in *Proceedings of the National Academy of Sciences USA,* Vol. 104, No. 18, pages 7723–7728; May 2007.

HITOSHI NISHIMURA (*woman on stool*) AND HUNTLEY HEDWORTH (*modern kitchen*) *Getty Images*

Depressingly Easy

We nuke prepared dishes rather than growing our own food and machine-wash ready-made clothes rather than sewing and scrubbing. Such conveniences may be contributing to rising rates of depression by depriving our brains of their hard-earned rewards **By Kelly Lambert**

For several decades, the multibillion-dollar antidepressant industry has pointed to imbalances in the neurochemical serotonin as the cause of depression. But research has yet to find convincing evidence that serotonin imbalances represent the indisputable cause of depression, and despite the unprecedented number of pharmacological treatment options available today, depression rates are higher than ever.

If Big Pharma does not have a cure for depression, shouldn't we pursue a fresh approach to this vexing problem? Could there be a nonpharmacological treatment strategy that would bring relief to the increasing number of people struggling with this mood disorder, for instance? What do we know about how to preserve good mental health? Is it possible to maintain a sense of control over our increasingly stressful daily lives, so that we can refocus our attention on more meaningful psychological endeavors, such as the challenging issues of problem solving and planning for our futures?

Is there something about how we live today that's actually toxic to our mental health? Were earlier generations somehow less susceptible to depressive symptoms? If so, what can we learn from how they lived that will help us rebuild our resilience and emotional well-being? To build a new, more integrated theory of depression, I have searched the literature for possible evolutionary triggers of emotional responses, reevaluated what we know about how the brain functions in both healthy and unhealthy ways, and identified pivotal lifestyle factors that might be affecting our society adversely.

Did we lose something vital when we started

I began thinking about the impact our contemporary lifestyle has on our mental health more than 10 years ago, after attending a lecture by Martin Seligman, a psychologist and the pioneering creator of the Positive Psychology movement, who was then president of the American Psychological Association. Seligman described two studies conducted in the 1970s in which people in different age groups were questioned about bouts of depression they had experienced during their lifetimes. The researchers then compared the responses of different generations.

The result should be a no-brainer, I thought at the time. Of course, older people would report more bouts of depression. After all, they had lived through the Great Depression and two world wars and suffered far more hardships and loss just by virtue of having lived longer. How could their mental anguish compare with the shorter (so far), easier and much less traumatic lives of a younger generation?

To my surprise, the exact opposite was true. Seligman reported that younger people were much more likely to have experienced depression. In fact, one study found that those born in the middle third of the 20th century were 10 times more likely to suffer from major depression than those born in the first third of the century were. These findings were later corroborated in a second study.

What is behind this startling disparity? For one thing, earlier generations did far more physical work than we do today. I was reminded of just how much our daily lives have changed six years ago, while reading a bedtime story to my younger daughter, who was three at the time. Skylar had chosen *Little House on the Prairie* for that evening—one of my childhood favorites.

Yesterday and Today

Over the years as I've read to my daughters I've often used the time to think through my to-do list for the next day. This bit of cognitive multitasking was a piece of cake with books such as *Goodnight Moon,* which I had read countless times when my girls were younger. "Goodnight room".... I need to update that section in Wednesday's lecture. "Goodnight moon".... and remember to take the chicken breasts out of the freezer. "Goodnight cow jumping over the moon".... I have to finish those analyses of the rat brains in the lab tomorrow. "Goodnight light".... I need to sign that permission slip for my older daughter Lara's field trip.

But that night the story about life on the prairie somehow drew me in. I found the demanding lives of Ma and Pa Ingalls so compelling that I actually had to pay attention! Laura Ingalls Wilder, their daughter, described in detail how the family planted, harvested and hunted down all their food throughout the year. That made my trips to the supermarket and merely reading the heating instructions for much of the food I "prepared" seem, well, lame.

I had always complained about doing laundry, but my efforts paled in comparison to those of Ma Ingalls. She had to scrub every garment on a washboard and then hang the clothes out to dry. And she had made all the garments with her own hands! Bathing my daughters did not require collecting rainwater or drawing water from a well; I merely had to turn on a faucet. The Ingalls family had to make most of the things I simply purchased, including toys, candles, soap, honey and butter. *Little House* crashed this working mom's self-pity party that evening. My life is a walk in the park compared with the lifestyles of a century earlier, I realized.

Clearly, I'm not suggesting that we go back to churning butter and tanning hides. But I do think we have to examine whether our cushy, digitally driven contemporary lifestyles—replete with SUVs, DVDs, laptops, cell phones and, yes, microwave ovens—may be at the root of the soaring

FAST FACTS

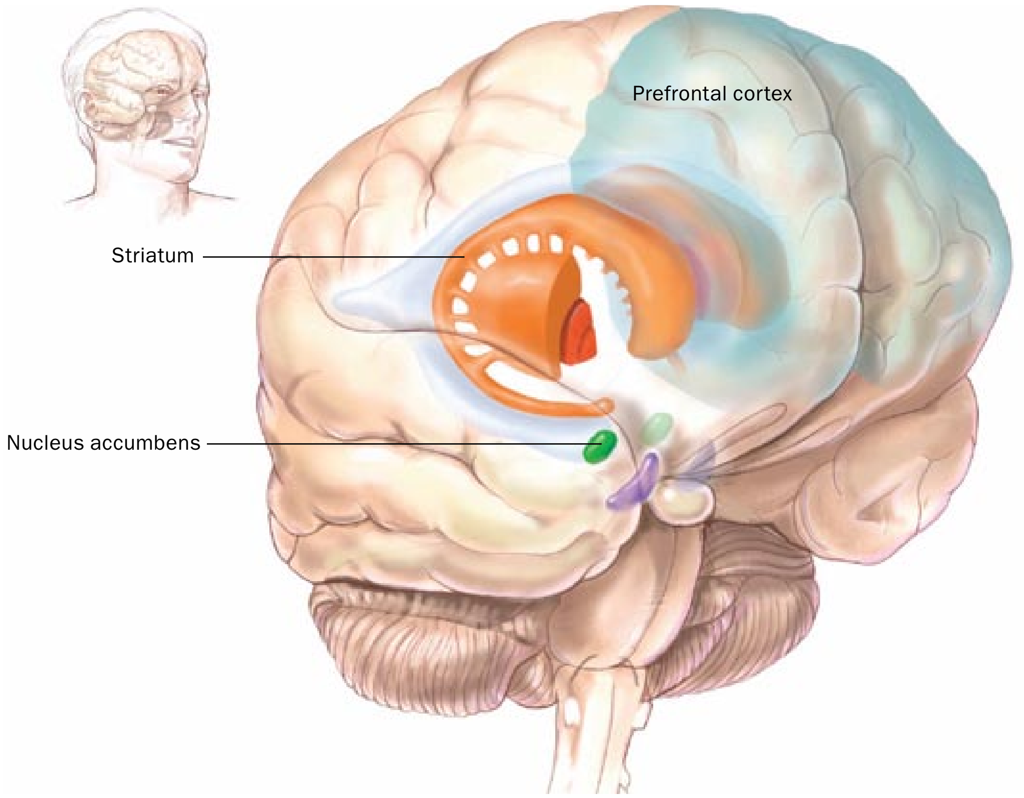
The Mental Perils of Ease

1» Rates of depression have risen in recent decades, at the same time that people are enjoying time-saving conveniences such as microwave ovens, e-mail, prepared meals, and machines for washing clothes and mowing lawns.

2» People of earlier generations, whose lives were characterized by greater efforts just to survive, paradoxically, were mentally healthier. Human ancestors also evolved in conditions where hard physical work was necessary to thrive.

3» By denying our brains the rewards that come from anticipating and executing complex tasks with our hands, the author argues, we undercut our mental well-being.

pushing buttons instead of plowing fields?



The nucleus accumbens, the brain's pleasure center, forms a critical interface between the motor system, or striatum, and the prefrontal cortex, which controls thought processes.

TERESE WINSLOW

rates of depression in people born in the latter part of the 20th century. Did we lose something vital to our mental health when we started pushing buttons instead of plowing fields? From a neuroanatomical point of view, I believe the answer is an emphatic yes.

Will Work for Pleasure

Our brains are programmed to derive a deep sense of satisfaction and pleasure when our physical effort produces something tangible, visible and—this fact is extremely important—meaningful in gaining the resources necessary for survival. In fact, our brains have been hardwired for this type of meaningful action since our ancestors were dressed in pelts. After all, nature needed a way to keep the earliest humans from becoming "cave potatoes." Hanging out all day didn't put freshly caught game on the campfire or help maintain a safe place to live.

I call this emotional payoff "effort-driven rewards." There are other important benefits to this type of effort beyond a greater sense of psychological well-being. We also experience an increased perception of control over our environment, more positive emotions and, perhaps most critical, enhanced resilience against mental illnesses such as depression.

Think about effort-driven rewards as a clever evolutionary tool, a way to motivate early humans to maintain the physical activity needed to obtain the resources to live—to find food, protect themselves from the elements and procreate to continue the species. Effort-driven rewards don't come just from physical effort, however. They also involve complex movement coupled with intricate thought processes. Imagine thousands of years ago, when our ancestors were tracking a pack of wild boars through a forest or across a plain. Because these animals are such vicious fighters, a successful strategy typically involved the coordinated efforts of a few hunters, requiring effective social communication and support. They needed to be wily as they chased their game or lured their prey into a trap that they had built. All their efforts were fueled by anticipation. In fact, anticipating something pleasurable creates more activity in the pleasure center of the brain than actually achieving the goal does. Once they caught their prey, our hunters were suffused with a sense of accomplishment and satisfaction as they skinned the animal before dinner.

Our hands play a crucial role when it comes to effort-driven rewards. From an evolutionary perspective, it is easy to see why they have always been so critical to our survival: they allow us to gain control of our environment. In fact, an essential premise of the proposed effort-driven-rewards theory is that movement—and especially hand movements that lead to desired outcomes—plays a key role in both preventing the onset of and building resilience against depression and other emotional disorders. Furthermore, we are predisposed to preferring hand movements that our ancestors needed for survival—those necessary for nurturing, cleaning, cooking, grooming, building shelter and farming.

But these days we shop at Whole Foods and drive Hummers. What does all this history have to do with our modern lives and depression? Our brains are generally the same size and have all the same parts and chemical composition as those of the earliest humans. Even though our lifestyles have changed radically, we have retained the innate need for achieving effort-driven rewards.

Is it okay that we have systematically removed physical effort—and all the complexity of movement and thought processes that it implies—from effort-driven rewards? Is contemporary society actually robbing us of certain forms of pleasure so fundamental to our mental health?

How Our Brains Reward Effort

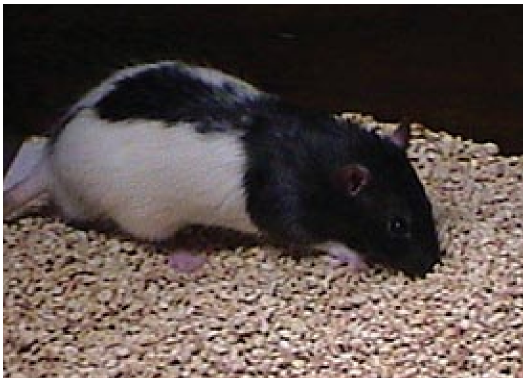
As I looked for the possible evolutionary triggers of depression, I also began to reexamine the primary symptoms. Over the past few decades researchers have identified certain areas of the brain associated with some of these symptoms. But could I match every single one—including loss of pleasure, feelings of worthlessness, slowed motor abilities and difficulty concentrating—to a specific part of the brain? And, significantly, were those different brain areas interconnected or linked in some clearly identifiable way?

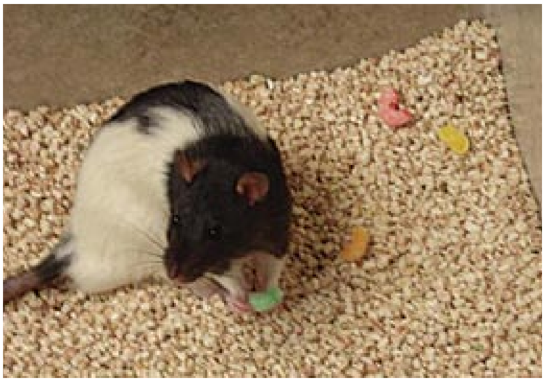
A natural place to start was the nucleus accumbens. This peanut-size structure is known as

The more the effort-driven-rewards system is

Hard work with hands is a likely factor in keeping the rate of depression in Amish communities far lower than it is in the rest of the U.S.

KEN GIGLIOTTI AP Photo/CP, *Winnipeg Free Press*





"Working rats" that had to search for hidden cereal learned to be persistent (*left*), which helped them solve new challenges; in contrast, "trust fund rats," which did not have to work for treats, gave up more easily (*right*).

MOLLY HYER

the pleasure, or reward, center of the brain, and it keeps us engaged in behaviors that are important to our survival, including eating and having sex. It plays a crucial role in how the brain functions, as it determines how to respond to environmental stimuli such as a piece of chocolate cake or that handsome guy at the bar.

An integrating center of the brain, it receives inputs and outputs from many neural areas. But for our purposes, I am focusing on its intimate connection to three other primary areas. The accumbens is positioned in proximity to the brain's motor system, or striatum, which controls our movements, and the limbic system, a collection of structures involved in emotion and learning. Essentially, the accumbens is a critical interface between our emotions and our actions. The closely linked motor and emotional systems also extend to the prefrontal cortex, which controls our thought processes, including problem solving, planning and decision making.

It is this accumbens-striatal-cortical network—the crucial system that connects movement, emotion and thinking—that I call the effort-driven-rewards circuit. It is the proposed neuroanatomical network underlying the symptoms associated with depression. In fact, it is possible to correlate every symptom of depression with a brain part on this circuit. Loss of pleasure? The nucleus accumbens. Sluggishness and slow motor responses? The striatum. Negative feelings? The limbic system. Poor concentration? The prefrontal cortex.

As if to impart renewed energy to our behavior, the motor structures that control our movements are intimately connected to the reward center—where we register pleasure—and to the cortical area of our brain that controls higher thought processes. Because of the interconnectivity of the brain areas that control movement, emotion and thinking, doing activities that involve a number of these components fully engages the effort-driven-rewards circuit.

In fact, the more the effort-driven-rewards circuit is kept activated and humming, the greater the sense of psychological well-being that results. It is as if an electric current is coursing through the network. When it is buzzing at top capacity—when, for example, installing that new light fixture requires both hands—the cells in those areas of the brain are turned on and secreting neurochemicals, such as dopamine and serotonin, which are involved in generating positive emotions. Neural connections are strengthened and reinforced. Perhaps most important, this kind of meaningful action—that is, effort-driven rewards—likely stimulates neurogenesis, the production of new brain cells. Neurogenesis is believed to be an important factor in recovering from depression.

Our hands play a crucial role. They occupy most of the real estate of the motor cortex, located in the higher cortex (the brain's outer covering). In fact, our hands are so important that moving them activates larger areas of the brain's complex cortex than does moving much larger parts of our bodies, such as our backs or even our legs.

humming, the greater the sense of well-being.

(The Author)

Neuroscientist and psychologist KELLY LAMBERT (www.kellylambert.com) is chair of psychology at Randolph-Macon College.

Knitting a sweater or cropping images into shape for a scrapbook project can alleviate stress and engage the brain in ways that benefit mental health.

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Doing activities you find meaningful boosts

As I continued to delve into the scientific research on depression, I found myself thinking more and more about the role of hands-on work and effort-driven rewards in our mental lives. Could adding simple tasks to our daily repertoire of activities help maintain emotional resilience? For the answer, there was just one place to go—back to the laboratory.

The Trust Fund Rats

Because the rat brain has all the same parts as the human brain (it is just smaller and less complex), rodent models are a great starting place for mental health research. Could the rats tell me if there was anything to the connection between depression and physical effort?

Two undergraduate students, Kelly Tu and Ashley Everette, helped me design a study to test my theory. We put four mounds of cage bedding in the testing apparatus and buried a Froot Loop—a culinary favorite among my laboratory rodents—in each mound. We trained the rats to search the mounds for the treat, and each day we changed the positions of the mounds randomly. The animals soon learned that each new mound had a Froot Loop, so once they retrieved one prize they moved on to the next mound. I designed this task to mimic "harvesting"—picking fruit, vegetables or, in this case, Froot Loops from the "fields."

Within a few days the rats immediately approached the mounds and started digging for their prized cereal pieces. We trained these rats every day for five weeks so they would have ample opportunities to make associations between their physical effort and desired rewards.

Our control group consisted of rats that we also placed in this novel environment every day. But regardless of the physical effort they exerted, they received their Froot Loop rewards in a lump sum in the corner of the apparatus. My students enjoyed calling these rats the "trust fund rats" and the digging rats the "working rats."

In the next phase, we developed a puzzle that the rats had to learn to solve. We wanted to assess whether the worker rats or the trust fund rats were more persistent in problem solving. We put a Froot Loop in a plastic cat-toy ball, a novel toy stimulus that would be mildly threatening to the animals because it had a bell in it. We made certain that the coveted cereal piece would not fit through the openings. That meant that no matter how clever or bold the rat was, it would not be able to retrieve the reward in the test's three-minute time frame. Of course, the rats would not know this factor, so we could assess the amount of time they spent trying to get the treat. The task involved boldness and persistence—characteristics that serve us all well during challenging times.

To make this task official, Craig Kinsley, my colleague from the University of Richmond who collaborated on this project, suggested we call it the "novel manipulandum task." This sounded much more impressive than the "cat-toy test."

What did we find? Although we made sure that both groups had equivalent levels of "emotionality," or anxiety, before training began, we observed remarkable differences in how the animals approached the challenge task. The worker rats picked up the ball in their mouths and slung their heads from side to side, tossing the ball across the cage. They also tried to stick their tiny paws through the openings to obtain the reward. Although the trust funders were just as motivated to retrieve the Froot Loop (both groups were on the same food-restriction regime) and used similar strategies, they were not nearly as persistent.

In fact, the worker rats spent approximately 60 percent more time trying to obtain the Froot Loop reward and made 30 percent more attempts to do so than the control group did. In their own way, the worker rats were telling us that their prior training sessions had made them more confident that they could overcome the challenge and retrieve the reward.

As I considered these findings, I was reminded of the widely reported study conducted several decades ago by Seligman and his colleague, psychologist Steven F. Maier of the University of Colorado at Boulder. In this famous experiment, dogs gave up responding and problem solving after they realized they could not escape from cages in which they received mild shocks. The researchers referred to this effort-consequence disconnect as "learned helplessness." Could our findings, then, be called "learned persistence"?

Clearly, we had empirical evidence of the adaptive value of effort-based rewards. The simple behavior of digging in mounds of bedding for cereal rewards had given the rats the motivation and confidence to persevere on a completely different challenging task.

The Lifestyle-Depression Link

Even though our nervous systems have the same anatomical makeup and chemical composition as those of our ancestors—or even people who lived a mere century ago—we are clearly using our brains and our hands differently. The percentage of farmers in the workforce was 38 percent at the start of the 20th century but less than 3 percent at its end. Today many more of us are knowledge workers than physical laborers. There have been vast increases in service-related jobs, from 31 percent of the workforce in 1900 to 78 percent of all workers in 1999.

Of course, you may feel a sense of accomplishment when you zip through your cognitive to-do list. The pleasure derived from just intellectualizing a problem is rewarding because it activates the prefrontal cortex. But effort-driven rewards activate the problem-solving prefrontal cortex plus the movement-controlling striatum and the reward/motivation center known as the accumbens, leaving you with a fuller brain experience that prepares you for life's next challenge. The decreased brain activation associated with increasingly effortless-driven rewards may, over time, diminish your perception of control over your environment and increase your vulnerability to mental illnesses such as depression.

What can we do to protect ourselves against the onset or tenacious persistence of depression? Poring over a scrapbook project or knitting a sweater may distract you from the stress in your life and engage your brain in intense ways that are beneficial to your mental health. Going out to the park or gym to exercise, especially if you perceive the activity as meaningful, can also boost important, emotionally relevant neurochemicals such as serotonin and endorphins. Such activities may alter the brain in more meaningful ways than any dose of a single drug could accomplish. Why? Because they are performed within the context of your life. When you are faced with a challenge and embark on the dynamic process of deciding on an effective strategy, implementing the plan and observing the final desirable outcome, your brain takes note of these situations so that it can access similar response strategies in the future.

important, emotionally relevant neurochemicals.

Just as a gymnast needs to complete simple muscle repetitions before she can learn complex routines, we need ongoing, positive experience with simple effort-driven rewards to execute the complex mental gymnastics that enrich our mental lives. Anything that lets us see a clear connection between effort and consequence—and that helps us feel in control of a challenging situation—is a kind of mental vitamin that helps build resilience and provides a buffer against depression. M

(Further Reading)

- **Increasing Rates of Depression.** G. L. Klerman and M. M. Weissman in *Journal of the American Medical Association,* Vol. 261, No. 15, pages 2229–2235; April 21, 1989.
- **Learned Optimism: How to Change Your Mind and Your Life.** Martin E. P. Seligman. Pocket Books, 1992.
- **Rising Rates of Depression in Today's Society: Consideration for the Roles of Effort-Based Rewards and Enhanced Resilience in Day-to-Day Functioning.** Kelly G. Lambert in *Neuroscience and Biobehavioral Reviews,* Vol. 30, No. 4, pages 497–510; 2006.

The Hidden Power of SCENT

Far from being a weak and unimportant sense, our odor-detecting ability is surprisingly acute and shapes our social interactions in ways we do not consciously realize

By Josie Glausiusz

A tangle of tubes and polyurethane pouches binds a naked man and woman—he, paunchy and unperturbed, she, slim and similarly unself-conscious. This setup is not some esoteric sex game; it's "Smell Blind Date," an installation created by artist James Auger on display this past spring in New York City as part of the Museum of Modern Art's exhibition *Design and the Elastic Mind*. The PVC tubes—which run between the subjects' chests, with outlets extending to pouches attached to their noses, armpits and genitals—allow the man and woman to inhale each other's body odor through a wall that divides them. In theory, they are on a truly blind date, each undistracted by the other's looks, assessing the other's potential as a mating partner by his or her smell alone.

The human sense of smell is often seen as insignificant, dismissed as a distant also-ran to our keen eyesight or sensitive hearing. But this sense is keener and

ANTONIO M. ROSARIO *Getty Images* (*nose*); GETTY IMAGES (*unsmiling couple*); JUPITERIMAGES (*armpit and smiling couple*); ISTOCKPHOTO: JOE McDANIEL (*dirty socks*), JAKUB SEMENIUK (*lemons*), CHRISTINE GLADE (*urine sample*), OKTAY ORTAKCIOGLU (*rotten apple*), JANIS LITAVNIEKS (*smoke*)

Dogs' long, large snouts are superior odor detectors, enabling canines to track the scents of lost or missing people and elusive items such as drugs and bombs.

more influential on our species than many people realize. In particular, as Auger's fanciful art project illustrates, smell facilitates a variety of human social interactions, both casual and intimate. Indeed, people who lose their sense of smell often gain a new appreciation for its importance [see "When the Nose Doesn't Know," by Eleonore von Bothmer; Scientific American Mind, October/November 2006].

Much of this influence goes unnoticed because it falls under the radar of consciousness. For instance, research demonstrates that we subconsciously use smell to assess a person's likability, sexual attractiveness and emotional state. Through scent, people can distinguish stranger from friend, male from female and gay from straight. Thus, olfaction may facilitate reproduction and prevent risky encounters. "If you look at nature, you see that every living organism has some form of chemosensory detection mechanism" that enables it to sense threats at a distance, explains neuroscientist Johan Lundström of the Monell Chemical Senses Center in Philadelphia. By the same token, deficiencies in olfaction may contribute to social withdrawal, such as that which accompanies schizophrenia [*see box on page 44*].

FAST FACTS

Social Sense

1» The human sense of smell is often seen as insignificant, but this sense is keener and more influential on our species than many people realize.

2» Smell subconsciously facilitates a variety of human social interactions. People use smell to assess a person's likability, sexual attractiveness and emotional state. They can also use scent to distinguish a stranger from a friend, a male from a female and someone who is gay from someone who is straight.

3» Deficiencies in olfaction may contribute to social withdrawal, such as that which accompanies schizophrenia.

Gifted Sniffers

Not only have scientists long snubbed human smell as feeble, but laypeople—at least in the past century or so—have often discounted the importance of odors in human life and society. The rise of sanitation standards in the 19th century was accompanied by repugnance for the putrid miasmas of ages past. Or, as Auger puts it: "Smell was devalued by scientists and philosophers in the 19th century, because they considered it to be a bestial, animalistic sense."

After all, dogs and rats, for example, would easily dominate humans in any kind of sniffing competition. Bloodhounds bred for tracking scents have about 300 times the number of odor-detecting cells in their noses as humans do. And rats possess three times as many functional genes for the protein receptors that pick up scents. The snouts of dogs and rats are also better adapted to detect odors than humans' noses are, because they are long, have a greater surface area, and are equipped with a filtering apparatus that cleans, warms and humidifies inspired air. Dogs also sniff much faster than humans do, which could contribute to their superior ability to track a scent.

Humans do, however, have a remarkably sophisticated olfactory apparatus. When people smell, air currents infused with chemicals swirl up the nose, passing over the moist olfactory epithelium on the roof of the nasal cavity and its roughly 12 million odor-detecting cells. Tiny cilia on each olfactory cell are covered with proteins that grasp odor molecules as they enter the nose. Each odor-detecting cell bears one of about 350 different olfactory receptor proteins and is specialized for sensing a limited number of odorant molecules. These receptor proteins work in

GEOFF GRAHAM *Getty Images*

Recent research shows that the human sense of smell is keen enough to enable some types of navigation.

different combinations to enable people to detect at least 10,000 scents. Sensory nerves carry signals from the odor-detecting cells to the brain's olfactory bulb, which in turn relays information about the inhaled odors to other areas of the brain [*see box on next page*].

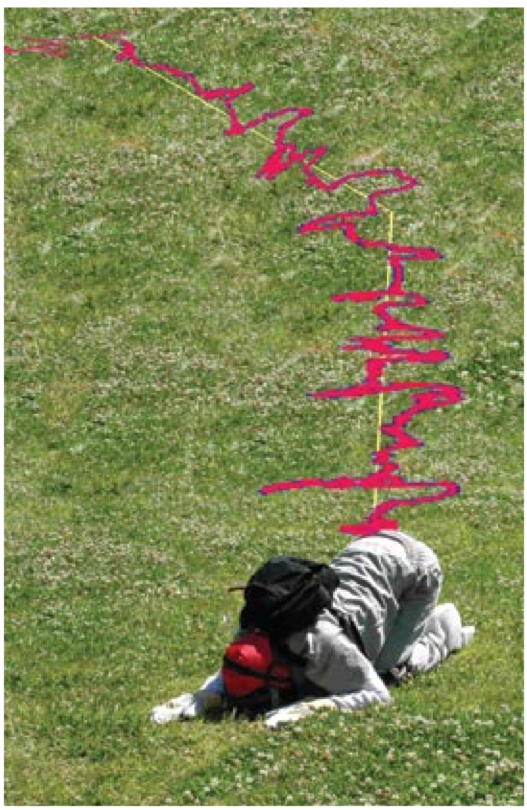
Scientists have recently revealed just how sensitive and versatile this odor-perception machinery is. An unusual experiment published in 2007 in *Nature Neuroscience* demonstrated that our sense of smell is keen enough to enable some types of navigation—and that this ability can improve with training. Neuroscientist Noam Sobel, along with his former graduate student, Jess Porter, both then at the University of California, Berkeley, and several colleagues, persuaded 32 undergraduates—16 men and 16 women—to don earmuffs and crawl blindfolded on hands and knees through a meadow, trying to track the scent from a rope coated in chocolate through the grass. Surprisingly, two thirds of the volunteers could follow the 33-foot twine line to the end, sniffing from side to side in a zigzag path, as a dog might. In a second experiment, two men and two women trained on the same trail three times a day for three days and cut their completion time from 10 to three and a half minutes by increasing their sniffing rate. The more they practiced, the faster they sniffed, and the faster they followed the trail.

This past March neurologist Jay Gottfried and his colleagues at Northwestern University published further evidence that humans can fine-tune their sense of smell. They asked people to sniff two very similar fragrant substances whose chemical structures were mirror images of each other. At first, nobody could tell the chemicals apart. But after the researchers paired the smell of one of the molecules with an electric shock, all the subjects learned to smell a difference between the two. The study shows that under certain conditions people can be acutely sensitive to minute differences in odors they might not otherwise be able to tell apart.

Not all humans smell equally well. According to cognitive neuroscientist Rachel Herz of Brown University, women are, on average, marginally more sensitive than men to trace odors and are most sensitive to odors when they are ovulating. A female's heightened sense of smell while fertile could aid in mate selection. In addition, a woman's acute sense of smell may improve her infants' chances of survival. Women can distinguish their babies' unique odors within an hour of birth, and two-day-old babies can identify their own mothers by smell—strategies that may help keep babies safely in their mothers' arms.

Identity by Scent

Although humans probably do not ordinarily use smell to navigate toward the nearest source of chocolate, we do seem to use odors—in most cases, subconsciously—to evaluate potential mates. Each of us has a unique scent: milky exudates of various glands, including the apocrine glands, which are located around the nipples, genitals and armpits, contain roughly 200 chemicals. The ratio of chemicals, which are metabolized into an aromatic brew by skin-dwelling bacteria, varies from person to person. Men and women, for example, have distinct odors governed by different ratios of sex hormones.



In one experiment, blindfolded people could follow a 33-foot chocolate-soaked piece of twine through a meadow (*red path*). With practice, they tracked the scent faster by increasing their sniffing rate.

SOURCE: "MECHANISMS OF SCENT-TRACKING IN HUMANS," BY J. PORTER ET AL., IN *NATURE NEUROSCIENCE*, VOL. 10, NO. 1; JANUARY 2007

Fragrances trigger subconscious responses in the brain before eliciting a conscious perception of an odor.

Neurons that convey odors from the nose to the brain's olfactory bulb have close connections with the oldest areas of the human brain: the limbic system, the region that includes the amygdala, which governs emotions such as aggression and fear, and the hippocampus, which controls memory acquisition. Thus, odors trigger subconscious emotional responses before arriving at the brain's outermost section, the cerebral cortex, for conscious assessment. What this means, Lundström explains, is that "a great deal of processing odor is done on a nonconscious basis."

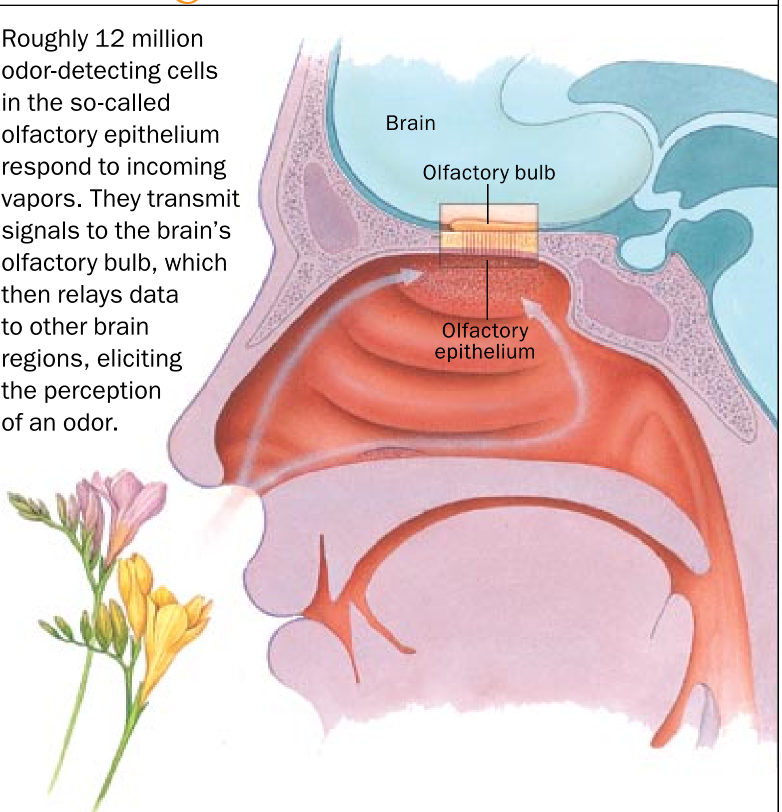
One trait that people may be subconsciously evaluating through scent is immune system status. Some studies suggest that variations in the major histocompatibility complex (MHC)—a gene region coding for cell-surface proteins that help our immune system distinguish our own cells from those of invaders—can influence body odor. In a now classic 1995 experiment biologist Claus Wedekind of the University of Lausanne in Switzerland and his colleagues demonstrated that women can determine the status of a man's immune system by sniffing his body odor. When women rated the odors of T-shirts men had slept in for two nights, they consistently preferred the scents of the men whose MHC genes differed significantly from their own, the researchers found. (Men could also differentiate MHC genes by smell.) This tendency may be adaptive: a mixing of divergent MHC genes through mating may lead to a more robust immune system in the resulting children than would occur from the mixing of similar MHC genes.

In a 2006 study experimental psychologist Bettina Pause of Heinrich Heine University in Düsseldorf, Germany, and her colleagues showed that the brain does indeed differentiate among the aromas of divergent immune systems. Pause collected armpit hair from 61 donors whom she had instructed to wash their armpits only with water and to avoid eating smelly foods such as onions and garlic for two days beforehand. She then had 40 volunteers sniff the hair while electrodes monitored the electrical peaks and valleys of their brain activity. The researchers found that the odors of donors whose MHC genes were similar to those of the sniffers provoked both faster and stronger electrical responses in the sniffers' brains than did the odors of those with dissimilar MHC DNA. "The smell helps us avoid those people who are [immunologically] similar to us; thereby, inbreeding is prevented," Pause explains. "Thus, the smell does not lead us to the right person but helps us avoid the wrong person."

Sniffing may enable us to pick out partners of a certain sexual orientation. In a 2005 study psychologist Yolanda Martins and sensory neuroscientist Charles Wysocki of the Monell Chemical Senses Center asked six heterosexual men, six gay men, six heterosexual women and six lesbians to wear cotton gauze pads under their armpits for three days. After collecting the pads, Martins and Wysocki had 80 volunteers—of both sexes, gay and straight—to take a big sniff of the gauze (whose wearers were not identified) and to report which pads smelled best. They found that heterosexual men and women and lesbians preferred the odor of the heterosexual men

Sensing Scents

Roughly 12 million odor-detecting cells in the so-called olfactory epithelium respond to incoming vapors. They transmit signals to the brain's olfactory bulb, which then relays data to other brain regions, eliciting the perception of an odor.



ROBERTO OSTI

and women to that of gay men, whereas gay men favored the odor of other gay men. Heterosexuals of both sexes and lesbians also liked the scents of lesbians better than those of gay males. (Gay men apparently have a distinctive odor for reasons that are, at present, largely speculative.)

But do particular human odors provoke sexual responses? Other animals secrete chemicals called pheromones that evoke a physiological or behavioral response in another member of the same species. For example, a compound called androstenone can drive female pigs into a frenzy of lust. Such an obvious behavioral effect of an odor has never been documented in humans. At least two nongaseous compounds, however, one exuded by men and one by women, do seem to elicit distinctive brain patterns of activity in men and women, indicating a possible divergence in their meaning to each sex, according to recent findings by neuroscientist Ivanka Savic of Karolinska University Hospital in Stockholm and her colleagues.

One of these chemicals—androstadienone, which is found in male sweat and semen—may help put women in the mood. In 2007 neuroscientists Claire Wyart of the University of California, Berkeley, and Noam Sobel, now at the Weizmann Institute of Science in Israel, reported that the smell of androstadienone was more likely than whiffs of baker's yeast were to improve mood and increase sexual arousal in 21 heterosexual women. Androstadienone also boosted levels of cortisol, a stress hormone, in the women's saliva. "It's the first report to my knowledge showing that smelling a specific component of male sweat was inducing significant changes in the hormonal balance of women," Wyart says.

Smelling Fear

Not everyone believes that androstadienone or any other substance qualifies as a human pheromone. For one thing, the perceptible amount of androstadienone in human sweat is extremely low—much lower than the concentrations used in scientific experiments. Many people cannot smell androstadienone at all; others find the smell sickening, which also argues against its utility as a sexual attractant. Nevertheless, some evidence suggests that humans may detect pheromones through nerves distinct from those that govern smell [see "Sex and the Secret Nerve," by R. Douglas Fields; Scientific American Mind, February/March 2007].

Body odor also has nonsexual effects on human interactions, including the ability to signal mood. Psychologist Denise Chen of Rice University and her colleagues asks subjects to watch funny or scary movies while wearing gauze pads inserted into their armpits. She then collects the pads, stuffs them into bottles and asks other people to sniff them. In a 2000 study, for example, Chen and Jeannette Haviland-Jones of Rutgers University found that volunteers could reliably identify "the odor of people when they are afraid" versus "the odor of people when they are happy." That is, humans can differentiate "happy" from

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Men and women have distinct odors, governed by different ratios of sex hormones. Each one of us also possesses a unique scent. The sexes subconsciously size each other up using smell.

(The Author)

JOSIE GLAUSIUSZ is a journalist living in New York City. Her articles have appeared in *Discover, OnEarth, Nature, Wired* and *Natural History.* She is co-author, with photographer Volker Steger, of *Buzz: The Intimate Bond between Humans and Insects* (Chronicle, 2004).

"fear" scents at a rate better than chance when asked to do so, even though they are not consciously aware of the emotional content of each of these smells when experienced in isolation.

The emotion elicited by the odor can even alter behavior. In a 2006 experiment the researchers found that subjects smelling "fear sweat" improved their performance on a word association test as compared with those who either smelled sweat from people who were not scared or sniffed a clean pad. In other words, Chen says, human chemical signals of fear may serve as a warning sign, provoking vigilance and sharpening wits. "It's been widely shown that chemical signals of fear and alarm are really powerful messages in the lives of many animals; they increase cautious behavior in recipient animals of the same species," she says. "I suspect that in humans there might be some effect similar to that. It's possible that they are more vigilant on these tasks and thus are performing more accurately."

After all, smell enables us to avoid various types of danger: to detect rotting food or toxic gases or even—as Lundström and his colleagues showed in a 2007 study—the odor of a stranger. In this study, which was the first to use imaging to examine how the brain responds to body odor, the researchers used positron-emission tomography, which measures glucose metabolism in different areas of the brain, to peer into the brains of 15 healthy nonsmoking women while they sniffed each of three aromas: their own body odor; the body odor of a longtime friend; and the odor of a stranger. Each scent had accumulated in cotton pads sewn into the armpits of tight T-shirts, which participants wore for seven con-

Anosmic and Aloof

If smell is integral to relationships and social cues, could its impairment lead to social withdrawal? Psychiatrist and smell researcher Dolores Malaspina of New York University and her colleagues at the New York State Psychiatric Institute have tried to answer that question by measuring the olfactory competence—in particular, the ability to identify odors—of people with schizophrenia, many of whom withdraw socially, interacting very little if at all with others.

Schizophrenia patients who withdraw socially have marked difficulty identifying common odors, such as those from pizza, smoke and chocolate.

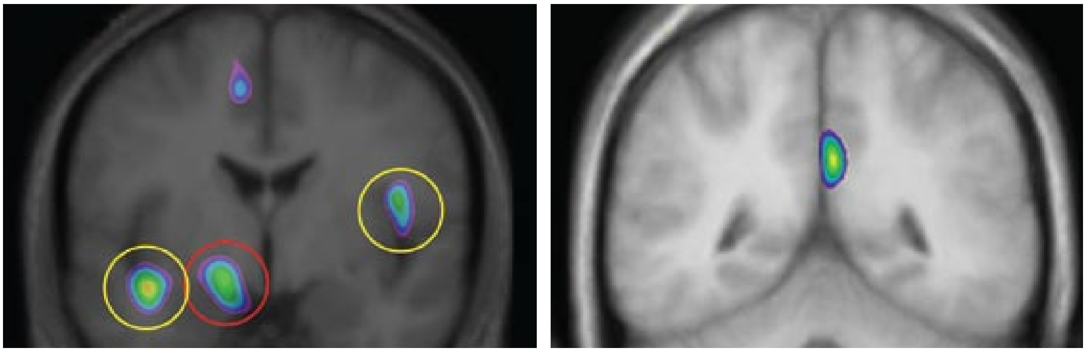
VASKO MIOKOVIC *iStockphoto* (*pizza*); NEWPHOTOSERVICE (*cigarette*); CHRISTINE BALDERAS *iStockphoto* (*chocolate*)

In a 2003 study Malaspina and her colleagues found that 70 schizophrenia patients scored significantly lower than 68 healthy subjects on a test requiring them to identify 40 common odors, such as the scents of chocolate, pizza, smoke and lilac. In addition, a subset of schizophrenia patients with diminished social drive—characterized by social withdrawal, self-neglect, poor speech and loss of motivation—scored worse than those who exhibited fewer social deficits. The worse the social deficit, the lower the scores on the smell identification test.

And in a 2005 investigation Malaspina and her colleagues found a similar association between an inability to identify odors and social isolation among 26 adolescents with early-onset psychosis, in which a person loses contact with reality, suffering delusions and hallucinations. The young patients who displayed typical schizophrenia symptoms, including social withdrawal, were more likely to have a marked difficulty identifying odors than those who suffered from psychotic symptoms of bipolar disorder, none of whom had an impaired sense of smell. Such findings suggest—but do not prove—that the smell impairment impedes social function. Schizophrenia might, after all, destroy areas of the brain that control both social motivation and smell. (Neurodegenerative diseases such as Alzheimer's and Parkinson's often destroy the ability to smell.)

Malaspina and New York State Psychiatric Institute research associate Deborah Goetz and their colleagues are now trying to pinpoint the neural origins of the putative deficits in smell and sociability. Ongoing studies are hinting that people with schizophrenia have impairments in the brain's inferior prefrontal cortex, which governs social behavior and motivation.

Malaspina hopes that her research will lead to new schizophrenia treatments, some of which might enhance social skills by sharpening the sense of smell. "It's really through the sense of smell that most mammals build social relationships," she argues. "The olfactory brain is really the social brain." —*J.G.*



A stranger's odor activates the amygdala (*circled in red at left*) and insula (*yellow circles*), which process emotions such as fear. A friend's scent perks up the retrosplenial cortex (*right image*).

COURTESY OF JOHAN LUNDSTRÖM *Monell Chemical Senses Center*

> Our sense of smell enables us to detect various types of danger, including the potential threat of a stranger.

secutive nights as they slept. The pads were then encased in glass bottles for sniffing purposes.

The subjects could indeed identify their friend's scent: after sniffing each of the three odor-containing bottles, they correctly chose the one containing the friend's odor. (They picked the one emitting their own aroma with similar accuracy.) The participants also rated the smell of a stranger as more intense and less pleasant than that of their friend. What is more, their brains registered the difference between friends and strangers. The odor of a stranger activated the amygdala and the insula—which processes fear and disgust, among other emotions—whereas the smell of a friend triggered a response in the retrosplenial cortex, an area located at the brain's surface near the center of the head that encodes familiarity. "They are smelling a body odor they cannot identify," Lundström says, "and that in itself is a warning to the system: here comes an unknown individual."

Evidence also indicates that we use smell to help us decide whether we like a person. Few people are willing to stand close to someone who stinks, but research suggests that even at subliminal, undetectable levels, odors can influence our social preferences. In a 2007 study Gottfried and his colleagues exposed undergraduate students—18 women and 13 men—to three odors: one pleasant (lemon), one neutral (anisole) and one unpleasant (valeric acid, which smells like sweaty socks). The researchers then diluted each scent enough to make it undetectable and asked the participants to sniff the watered-down odors. After a whiff of each odor, the subjects judged a series of 20 faces on a 10-point scale from "extremely unlikable" to "extremely likable."

Even though the faces wore neutral expressions, the subjects rated a given set of faces as less likable if they had first sniffed the sweaty-smelling valeric acid (even though its odor was imperceptible) and more likable if they had inhaled the dilute lemony scent. "Human social judgments and social interactions are at least partly under the control of smells we can't perceive," Gottfried concludes.

Yet society continues to disdain the role that smell plays in everyday life. "It's a puritanical hangover from a Victorian attitude about civilization, how people who are civilized and have any valuable contribution should be scent-free for the most part," Herz says. Gottfried adds: "The human sense of smell is so often dismissed as being not only weaker than that of dogs or rats but really, truly inconsequential. That always gets my goat. If you take a harder look at the literature, all sorts of evidence suggests that the human nose is pretty damn good, actually." **M**

(Further Reading)

- **Aroma: The Cultural History of Smell.** Constance Classen, David Howes and Anthony Synnott. Routledge, 1994.
- **Human Body Odors and Their Perception.** Charles Wysocki and George Preti in *Japanese Journal of Taste and Smell Research,* Vol. 7, pages 19–42; 2000.
- **The Human Sense of Smell: Are We Better Than We Think?** Gordon M. Shepherd in *PLoS Biology,* Vol. 2, No. 5, pages 572–575; May 2004.
- **The Intensity of Human Body Odors and the MHC: Should We Expect a Link?** Claus Wedekind, Thomas Seebeck, Florence Bettens and Alexander J. Paepke in *Evolutionary Psychology,* Vol. 4, pages 85–94; 2006.
- **The Scent of Desire: Discovering Our Enigmatic Sense of Smell.** Rachel Herz. William Morrow, 2007.
- Monell Chemical Senses Center: **www.monell.org**
- Artist James Auger's Web site: **www.smellplus.co.uk**

The Secrets of STORYTE

Our love for telling tales reveals the workings of the mind

By Jeremy Hsu

When Brad Pitt tells Eric Bana in the 2004 film *Troy* that "there are no pacts between lions and men," he is not reciting a clever line from the pen of a Hollywood screenwriter. He is speaking Achilles' words in English as Homer wrote them in Greek more than 2,000 years ago in the *Iliad*. The tale of the Trojan War has captivated generations of audiences while evolving from its origins as an oral epic to written versions and, finally, to several film adaptations. The power of this story to transcend time, language and culture is clear even today, evidenced by *Troy*'s robust success around the world.

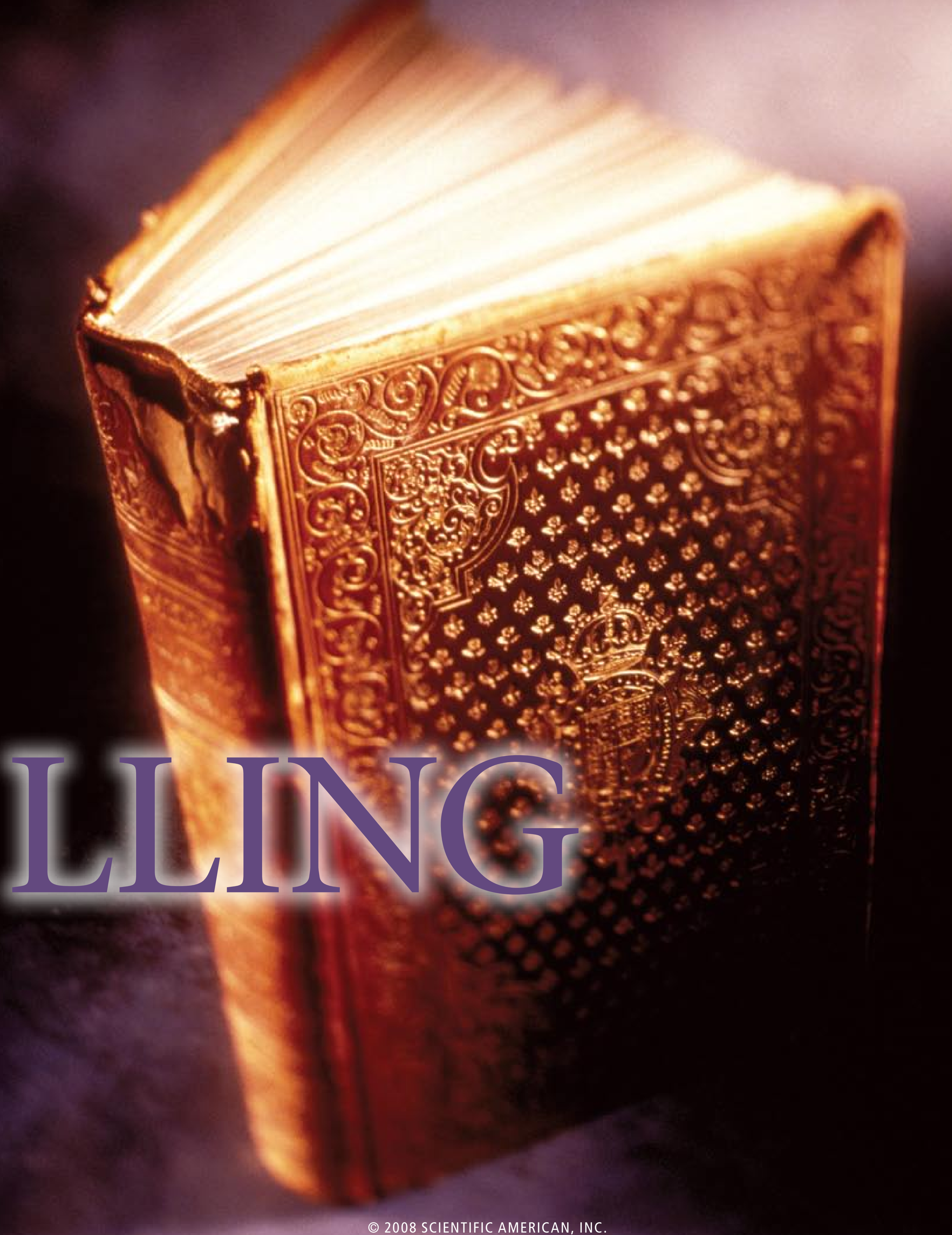
Popular tales do far more than entertain, however. Psychologists and neuroscientists have recently become fascinated by the human predilection for storytelling. Why does our brain seem to be wired to enjoy stories? And how do the emotional and cognitive effects of a narrative influence our beliefs and real-world decisions?

The answers to these questions seem to be rooted in our history as a social animal. We tell stories about other people and for other people. Stories help us to keep tabs on what is happening in our communities. The safe, imaginary world of a story may be a kind of training ground, where we can practice interacting with others and learn the customs and rules of society. And stories have a unique power to persuade and motivate, because they appeal to our emotions and capacity for empathy.

A Good Yarn

Storytelling is one of the few human traits that are truly universal across culture and through all of known history. Anthropologists find evidence of folktales everywhere in ancient cultures, written in Sanskrit, Latin, Greek, Chinese, Egyptian and Sumerian. People in societies of all types weave narratives, from oral storytellers in hunter-gatherer tribes to the millions of writers churning out books, television shows and movies. And when a characteristic behavior shows up in so many different societies, researchers pay attention: its roots may tell us something about our evolutionary past.

To study storytelling, scientists must first define what constitutes a story, and that can prove tricky. Because there are so many diverse forms, scholars often define story structure, known as narrative, by explaining what it is not. Exposition contrasts with narrative by being a simple, straightforward explanation, such as a list of facts or an encyclopedia entry. Another standard approach defines narrative as a series of causally linked events that unfold over time. A third definition hinges on the typical narrative's subject matter: the interactions of intentional agents—characters with minds—who possess various motivations.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Children develop "theory of mind," the ability to attribute thought to other entities, around age four or five. Such ability is crucial for social life—and for enjoying stories.

However narrative is defined, people know it when they feel it. Whether fiction or nonfiction, a narrative engages its audience through psychological realism—recognizable emotions and believable interactions among characters. "Everyone has a natural detector for psychological realism," says Raymond A. Mar, assistant professor of psychology at York University in Toronto. "We can tell when something rings false."

But the best stories—those retold through generations and translated into other languages—do more than simply present a believable picture. These tales captivate their audience, whose emotions can be inextricably tied to those of the story's characters. Such immersion is a state psychologists call "narrative transport."

Researchers have only begun teasing out the relations among the variables that can initiate narrative transport. A 2004 study by psychologist Melanie C. Green, now at the University of North Carolina at Chapel Hill, showed that prior knowledge and life experience affected the immersive experience. Volunteers read a short story about a gay man attending his college fraternity's reunion. Those who had friends or family members who were homosexual reported higher transportation, and they also perceived the story events, settings and characters to be more realistic. Transportation was also deeper for participants with past experiences in fraternities or sororities. "Familiarity helps, and a character to identify with helps," Green explains.

Other research by Green has found that people who perform better on tests of empathy, or the capacity to perceive another person's emotions, become more easily transported regardless of the story. "There seems to be a reasonable amount of variation, all the way up to people who can get swept away by a Hallmark commercial," Green says.

In Another's Shoes

Empathy is part of the larger ability humans have to put themselves in another person's shoes: we can attribute mental states—awareness, intent—to another entity. Theory of mind, as this trait is known, is crucial to social interaction and communal living—and to understanding stories.

Children develop theory of mind around age four or five. A 2007 study by psychologists Daniela O'Neill and Rebecca Shultis, both at the University of Waterloo in Ontario, found that five-year-olds could follow the thoughts of an imaginary character but that three-year-olds could not. The children saw model cows in both a barn and a field, and the researchers told them that a farmer sitting in the barn was thinking of milking the cow in the field. When then asked to point to the cow the farmer wanted to milk, three-year-olds pointed to the cow in the barn—they had a hard time following the character's thoughts to the cow in the field. Five-year-olds, however, pointed to the cow in the field, demonstrating theory of mind.

Perhaps because theory of mind is so vital to social living, once we possess it we tend to imagine minds everywhere, making stories out of everything. A classic 1944 study by Fritz Heider and Mary-Ann Simmel, then at Smith College, elegantly demonstrated this tendency. The psy-

FAST FACTS

Once upon a Time

1» Storytelling is a human universal, and common themes appear in tales throughout history and all over the the world.

2» These characteristics of stories, and our natural affinity toward them, reveal clues about our evolutionary history and the roots of emotion and empathy in the mind.

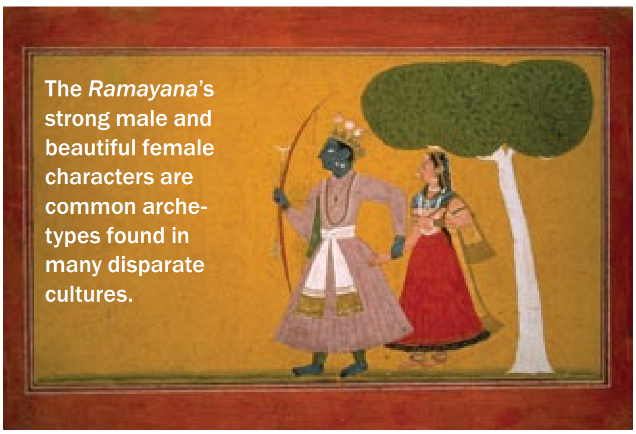
3» By studying narrative's power to influence beliefs, researchers are discovering how we analyze information and accept new ideas.

PRECEDING PAGES: HARRY GIGLIO *jupiterimages*; THIS PAGE: JORGEN SCHYTTE *Peter Arnold, Inc.*

The imaginary world of stories may serve as a proving ground for vital social skills.

chologists showed people an animation of a pair of triangles and a circle moving around a square and asked the participants what was happening. The subjects described the scene as if the shapes had intentions and motivations—for example, "The circle is chasing the triangles." Many studies since then have confirmed the human predilection to make characters and narratives out of whatever we see in the world around us.

But what could be the evolutionary advantage of being so prone to fantasy? "One might have expected natural selection to have weeded out any inclination to engage in imaginary worlds rather than the real one," writes Steven Pinker, a Harvard University evolutionary psychologist, in the April 2007 issue of *Philosophy and Literature*. Pinker goes on to argue against this claim, positing that stories are an important tool for learning and for developing relationships with others in one's social group. And most scientists are starting to agree: stories have such a powerful and universal appeal that the neurological roots of both telling tales and enjoying them are probably tied to crucial parts of our social cognition.



The *Ramayana*'s strong male and beautiful female characters are common archetypes found in many disparate cultures.

RAMA AND SITA (PAHARI SCHOOL, CIRCA 1740), VICTORIA & ALBERT MUSEUM, LONDON/ART RESOURCE, NY

As our ancestors evolved to live in groups, the hypothesis goes, they had to make sense of increasingly complex social relationships. Living in a community requires keeping tabs on who the group members are and what they are doing. What better way to spread such information than through storytelling?

Indeed, to this day people spend most of their conversations telling personal stories and gossiping. A 1997 study by anthropologist and evolutionary biologist Robin Dunbar, then at the University of Liverpool in England, found that social topics accounted for 65 percent of speaking time among people in public places, regardless of age or gender.

Anthropologists note that storytelling could have also persisted in human culture because it promotes social cohesion among groups and serves as a valuable method to pass on knowledge to future generations. But some psychologists are starting to believe that stories have an important effect on individuals as well—the imaginary world may serve as a proving ground for vital social skills.

"If you're training to be a pilot, you spend time in a flight simulator," says Keith Oatley, a professor of applied cognitive psychology at the University of Toronto. Preliminary research by Oatley and Mar suggests that stories may act as "flight simulators" for social life. A 2006 study hinted at a connection between the enjoyment of stories and better social abilities. The researchers used both self-report and assessment tests to determine social ability and empathy among 94 students, whom they also surveyed for name recognition of authors who wrote narrative fiction and nonnarrative nonfiction. They found that students who had had more exposure to fiction tended to perform better on social ability and empathy tests. Although the results are provocative, the authors caution that the study did not probe cause and effect—exposure to stories may hone social skills as the researchers suspect, but perhaps socially inclined individuals simply seek out more narrative fiction.

In support for the idea that stories act as practice for real life are imaging studies that reveal similar brain activity during viewings of real people and animated characters. In 2007 Mar conducted a study using *Waking Life*, a 2001 film in which live footage of actors was traced so that the characters appear to be animated drawings. Mar used functional magnetic resonance imaging to scan volunteers' brains as they watched matching footage of the real actors and the corresponding animated characters. During the real footage, brain activity spiked strongly in the superior temporal sulcus and the temporoparietal junction, areas associated with processing biological motion. The same areas lit up to a lesser extent for the animated footage. "This difference in brain activation could be how

(The Author)

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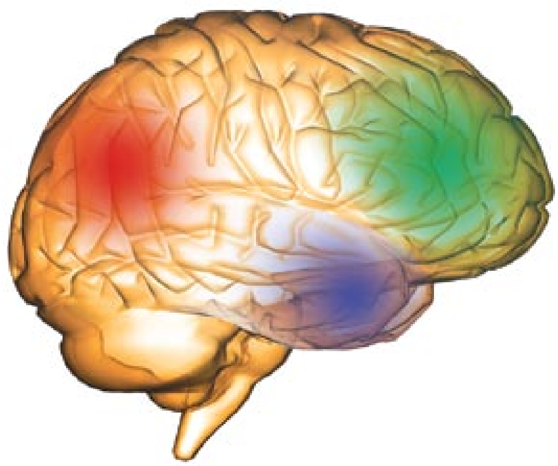
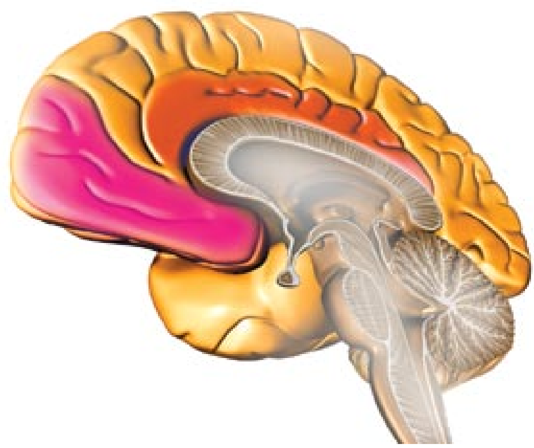
Tales in the Brain

Imaging studies have found much story-related activity in the brain's right hemisphere. Patterns for story processing differ from patterns for other related mental tasks, such as paying attention or stringing together sentences for language comprehension.

Raymond A. Mar, now at York University in Toronto, reviewed such imaging research in a 2004 paper. Areas that appear crucial to creating or understanding narrative include the medial (*pink*) and lateral (*green*) prefrontal cortex, home to working memory, which help to sequence information and represent story events. The cingulate cortex (*orange*) may be involved in adding visuospatial imagery and connecting personal experience with the story to add understanding.

Brain regions such as the medial prefrontal cortex, temporoparietal junction (*red*) and temporal poles (*purple*) may also work together to aid in the identification of characters' mental states. The ability to read other people's motivations and intentions enables not only our understanding of stories but, more crucially, the comprehension of real-life social situations—an undeniable evolutionary advantage for both individuals and groups alike. *—J.H.*





PASIEKA SPL/*Photo Researchers, Inc.*

we distinguish between fantasy and reality," Mar says.

As psychologists probe our love of stories for clues about our evolutionary history, other researchers have begun examining the themes and character types that appear consistently in narratives from all cultures. Their work is revealing universal similarities that may reflect a shared, evolved human psyche.

Boy Meets Girl …

A 2006 study by Jonathan Gottschall, an English professor at Washington & Jefferson College, found relevant depictions of romantic love in folktales scattered across space and time. The idea of romantic love has not been traditionally considered to be a cultural universal because of the many societies in which marriage is mainly an economic or utilitarian consideration. But Gottschall's study suggests that rather than being a construct of certain societies, romantic love must have roots in our common ancestry. In other words, romance—not just sex—has a biological basis in the brain.

"You do find these commonalities," Gottschall says. He is one of several scholars, known informally as literary Darwinists, who assert that story themes do not simply spring from each specific culture. Instead the literary Darwinists propose that stories from around the world have universal themes reflecting our common underlying biology.

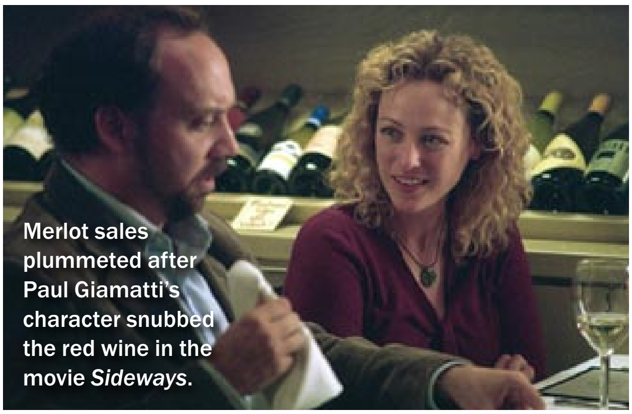
Another of Gottschall's studies published earlier this year reveals a persistent mind-set regarding gender roles. His team did a content analysis of 90 folktale collections, each consisting of 50 to 100 stories, from societies running the gamut from industrial nations to hunter-gatherer tribes. They found overwhelmingly similar gender depictions emphasizing strong male protagonists and female beauty. To counterbalance the possibility that male storytellers were biasing gender idealizations, the team also sampled cultures that were more egalitarian and less patriarchal.

"We couldn't even find one culture that had more emphasis on male beauty," Gottschall notes, explaining that the study sample had three times as many male as compared with female main characters and six times as many references to female beauty as to male beauty. That difference in gender stereotypes, he suggests, may reflect the classic Darwinian emphasis on reproductive health in women, signified by youth and beauty, and on the desirable male ability to provide for a family, signaled by physical power and success.

Other common narrative themes reveal our basic wants and needs. "Narrative involves agents pursuing some goal," says Patrick Colm Hogan, professor of English and comparative literature at the University of Connecticut. "The standard goals are partially a result of how our emotion systems are set up."

People accept ideas more readily when their minds are in story mode as opposed to an analytical mind-set.

Hogan does not consider himself a literary Darwinist, but his research on everything from Hindu epic poems such as the *Ramayana* to modern film adaptations of Shakespeare supports the idea that stories reveal something about human emotions seated in the mind. As many as two thirds of the most respected stories in narrative traditions seem to be variations on three narrative patterns, or prototypes, according to Hogan. The two more common prototypes are romantic and heroic scenarios—the former focuses on the trials and travails of love, whereas the latter deals with power struggles. The third prototype, dubbed "sacrificial" by Hogan, focuses on agrarian plenty versus famine as well as on societal redemption. These themes appear over and over again as humans create narrative records of their most basic needs: food, reproduction and social status.



Merlot sales plummeted after Paul Giamatti's character snubbed the red wine in the movie *Sideways*.

MERIE W. WALLACE *Fox Searchlight Pictures/The Kobal Collection*

Happily Ever After

The power of stories does not stop with their ability to reveal the workings of our minds. Narrative is also a potent persuasive tool, according to Hogan and other researchers, and it has the ability to shape beliefs and change minds.

Advertisers have long taken advantage of narrative persuasiveness by sprinkling likable characters or funny stories into their commercials. A 2007 study by marketing researcher Jennifer Edson Escalas of Vanderbilt University found that a test audience responded more positively to advertisements in narrative form as compared with straightforward ads that encouraged viewers to think about the arguments for a product. Similarly, Green co-authored a 2006 study that showed that labeling information as "fact" increased critical analysis, whereas labeling information as "fiction" had the opposite effect. Studies such as these suggest people accept ideas more readily when their minds are in story mode as opposed to when they are in an analytical mind-set.

Works of fiction may even have unexpected real-world effects on people's choices. Merlot was one of the most popular red wines among Americans until the 2005 film *Sideways* depicted actor Paul Giamatti as an ornery wine lover who snubbed it as a common, inferior wine. Winemakers saw a noticeable drop in sales of the red wine that year, particularly after *Sideways* garnered national attention through several Oscar nominations.

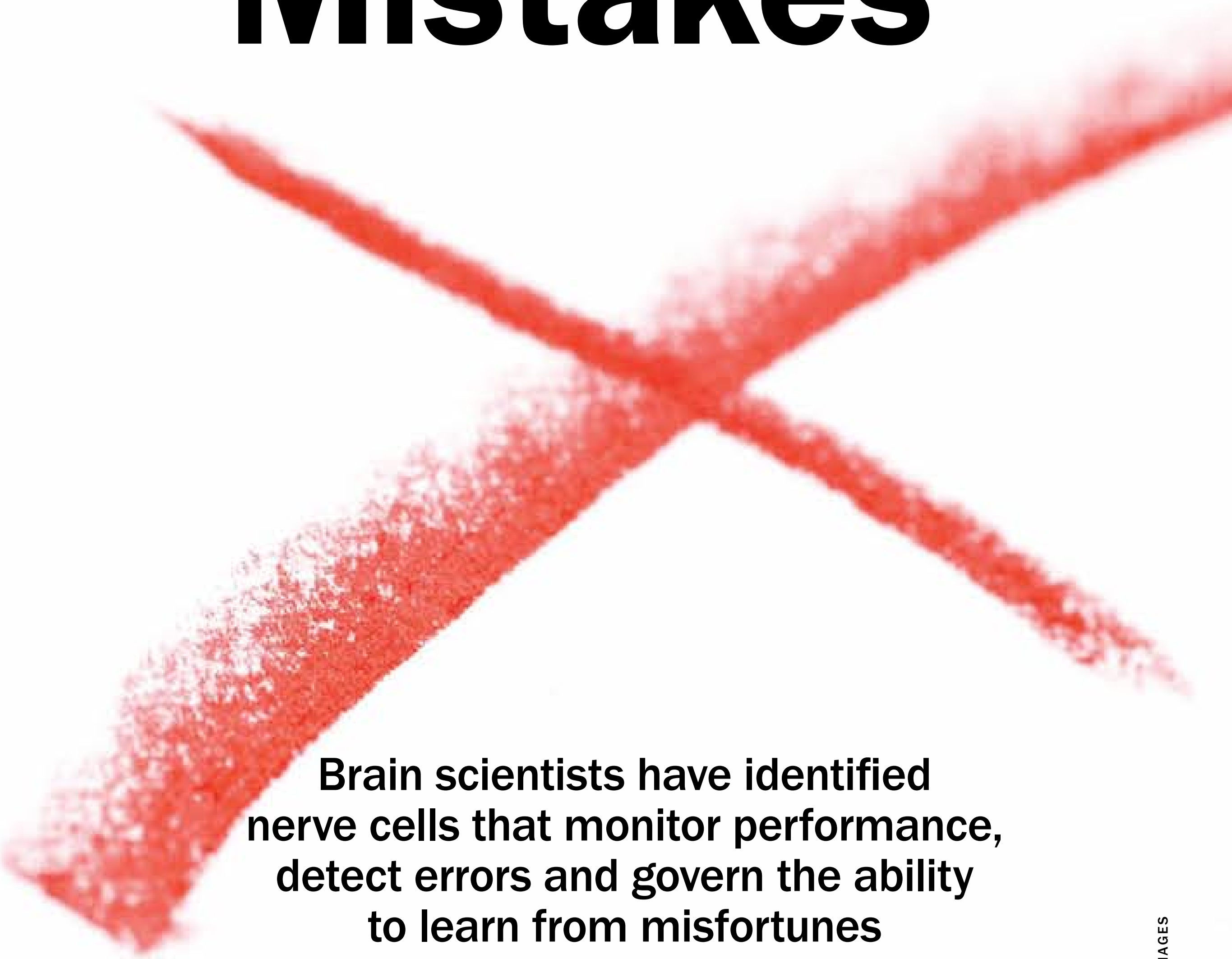
As researchers continue to investigate storytelling's power and pervasiveness, they are also looking for ways to harness that power. Some such as Green are studying how stories can have applications in promoting positive health messages. "A lot of problems are behaviorally based," Green says, pointing to research documenting the influence of Hollywood films on smoking habits among teens. And Mar and Oatley want to further examine how stories can enhance social skills by acting as simulators for the brain, which may turn the idea of the socially crippled bookworm on its head.

One thing is clear—although research on stories has only just begun, it has already turned up a wealth of information about the social roots of the human mind—and, in science, that's a happy ending. **M**

(Further Reading)

- **Why Fiction May Be Twice as True as Fact: Fiction as Cognitive and Emotional Simulation.** Keith Oatley in *Review of General Psychology,* Vol. 3, No. 2, pages 101–117; June 1999.
- **The Mind and Its Stories: Narrative Universals and Human Emotion.** Patrick Colm Hogan. Cambridge University Press, 2003.
- **Transportation into Narrative Worlds: The Role of Prior Knowledge and Perceived Realism.** Melanie C. Green in *Discourse Processes,* Vol. 38, No. 2, pages 247–266; 2004.
- **The Literary Animal: Evolution and the Nature of Narrative.** Edited by Jonathan Gottschall and David Sloan Wilson. Northwestern University Press, 2005.
- **Detecting Agency from the Biological Motion of Veridical *vs* Animated Agents.** R. A. Mar, W. M. Kelley, T. F. Heatherton and C. N. Macrae in *Social Cognitive and Affective Neuroscience,* Vol. 2, No. 3, pages 199–205; September 2007.

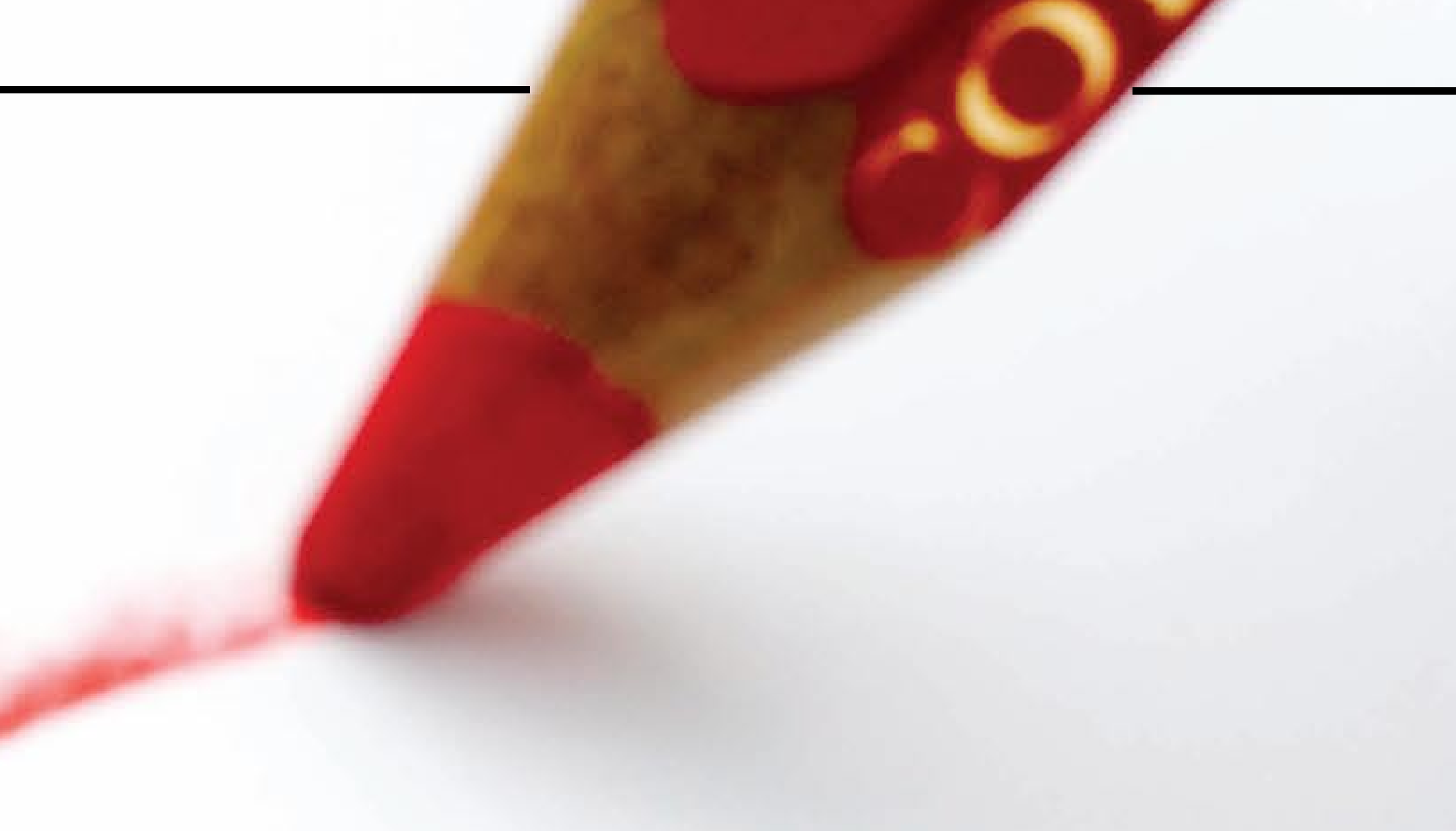
(Minding) Mistakes



Brain scientists have identified nerve cells that monitor performance, detect errors and govern the ability to learn from misfortunes

By Markus Ullsperger

GETTY IMAGES



April 26, 1986: During routine testing, reactor number 4 of the Chernobyl nuclear power plant explodes, triggering the worst catastrophe in the history of the civilian use of nuclear energy.

September 22, 2006: On a trial run, experimental maglev train Transrapid 08 plows into a maintenance vehicle at 125 mph near Lathen, Germany, spewing wreckage over hundreds of yards, killing 23 passengers and severely injuring 10 others.

Human error was behind both accidents. Of course, people make mistakes, both large and small, every day, and monitoring and fixing slip-ups is a regular part of life. Although people understandably would like to avoid serious errors, most goofs have a good side: they give the brain information about how to improve or fine-tune behavior. In fact, learning from mistakes is likely essential to the survival of our species.

In recent years researchers have identified a region of the brain called the medial frontal cortex that plays a central role in detecting mistakes and responding to them. These frontal neurons become active whenever people or monkeys change their behavior after the kind of negative feedback or diminished reward that results from errors.

Much of our ability to learn from flubs, the latest studies show, stems from the actions of the neurotransmitter dopamine. In fact, genetic variations that affect dopamine signaling may help explain differences between people in the extent to which they learn from past goofs. Meanwhile certain patterns of cerebral activity often foreshadow miscues, opening up the possibility of preventing blunders with portable devices that can detect error-prone brain states.

Error Detector

Hints of the brain's error-detection apparatus emerged serendipitously in the early 1990s. Psychologist Michael Falkenstein of the University of Dortmund in Germany and his colleagues were monitoring subjects' brains using electroencephalography (EEG) during a psychology experiment and noticed that whenever a subject pressed the wrong button, the electrical potential in the frontal lobe suddenly dropped by about 10

VIKTOR TOLOCHKO *ITAR-TASS/Corbis*

Minor mistakes can cause major damage, as occurred in the 1986 Chernobyl nuclear reactor accident.

microvolts. Psychologist William J. Gehring of the University of Illinois and his colleagues confirmed this effect, which researchers refer to as error-related negativity, or ERN [*see illustration on opposite page*].

An ERN may appear after various types of errors, unfavorable outcomes or conflict situations. Action errors occur when a person's behavior produces an unintended result. Time pressure, for example, often leads to misspellings while typing or incorrect addresses on e-mails. An ERN quickly follows such action errors, peaking within 100 milliseconds after the incorrect muscle activity ends.

A slightly more delayed ERN, one that crests 250 to 300 milliseconds after an outcome, occurs in response to unfavorable feedback or monetary losses. This so-called feedback ERN also may appear in situations in which a person faces a difficult choice—known as decision uncertainty—and remains conflicted even after making a choice. For instance, a feedback ERN may occur after a person has picked a checkout line in a supermarket and then realizes that the line is moving slower than the adjacent queue.

Where in the brain does the ERN originate? Using functional magnetic resonance imaging, among other imaging methods, researchers have repeatedly found that error recognition takes place in the medial frontal cortex, a region on the surface of the brain in the middle of the frontal lobe, including the anterior cingulate [*see illustration on page 56*]. Such studies implicate this brain region as a monitor of negative feedback, action errors and decision uncertainty—and thus as an overall supervisor of human performance.

In a 2005 paper, along with psychologist Stefan Debener of the Institute of Hearing Research

FAST FACTS

Error Alert

1» **The brain contains neural machinery for recognizing errors, correcting them, and optimizing behavior.**

2» **The neurotransmitter dopamine plays a major role in our ability to learn from our mistakes. Genetic variants that affect dopamine signaling may partly explain differences between people in the extent to which they learn from errors or negative consequences.**

3» **Certain patterns of cerebral activity often foreshadow errors, opening up the possibility of preventing blunders with portable devices that can detect error-prone brain states.**

The medial frontal cortex in the brain **spots our slipups** and governs our ability to learn from them.

in Southampton, England, and our colleagues, I showed that the medial frontal cortex is the probable source of the ERN. In this study, subjects performed a so-called flanker task [*see box on page 57*], in which they specified the direction of a central target arrow in the midst of surrounding decoy arrows while we monitored their brain activity using EEG and fMRI simultaneously. We found that as soon as an ERN occurs, activity in the medial frontal cortex increases and that the bigger the ERN the stronger the fMRI signal, suggesting that this brain region does indeed generate the classic error signal.

Learning from Lapses

In addition to recognizing errors, the brain must have a way of adaptively responding to them. In the 1970s psychologist Patrick Rabbitt of the University of Manchester in England, one of the first to systematically study such reactions, observed that typing misstrikes are made with slightly less keyboard pressure than are correct strokes, as if the typist were attempting to hold back at the last moment.

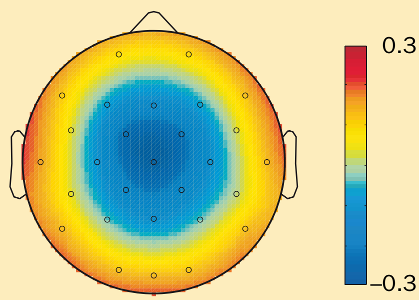
More generally, people often react to errors by slowing down after a mistake, presumably to more carefully analyze a problem and to switch to a different strategy for tackling a task. Such behavioral changes represent ways in which we learn from our mistakes in hopes of avoiding similar slipups in the future.

The medial frontal cortex seems to govern this process as well. Imaging studies show that neural activity in this region increases, for example, before a person slows down after an action error. Moreover, researchers have found responses from individual neurons in the medial frontal cortex in monkeys that implicate these cells in an animal's behavioral response to negative feedback, akin to that which results from an error.

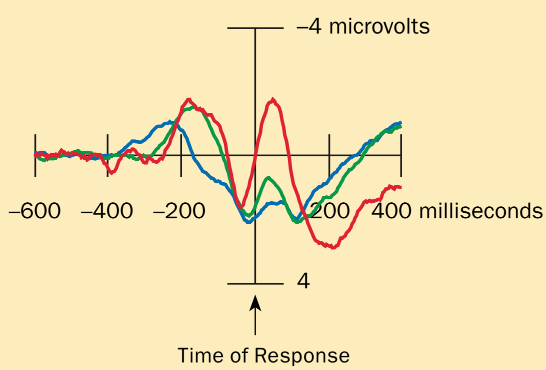
In 1998 neuroscientists Keisetsu Shima and Jun Tanji of the Tohoku University School of Medicine in Sendai, Japan, trained three monkeys to either push or turn a handle in response to a visual signal. A monkey chose its response based on the reward it expected: it would, say, push the handle if that action had been consistently followed by a reward. But when the researchers successively reduced the reward for pushing—a type of negative feedback or error signal—the animals would within a few trials switch to turning the handle instead. Meanwhile researchers were recording the electrical activity of single neurons in part of the monkeys' cingulate.

Shima and Tanji found that four types of neurons altered their activity after a reduced reward but only if the monkey used that reduction as a cue to push instead of turn, or vice versa. These neurons did not flinch if the monkey did not decide to switch actions or if it did so in response to a tone rather than to a lesser reward. And when the researchers temporarily deactivated neurons in this region, the monkey no longer switched movements after a dip in its incentive. Thus, these neurons relay information about the degree of reward for the purpose of altering behavior and can use negative feedback as a guide to improvement.

In 2004 neurosurgeon Ziv M. Williams and his colleagues at Massachusetts General Hospital reported finding a set of neurons in the human anterior cingulate with similar properties. The researchers recorded from these neurons in five patients who were scheduled for surgical remov-

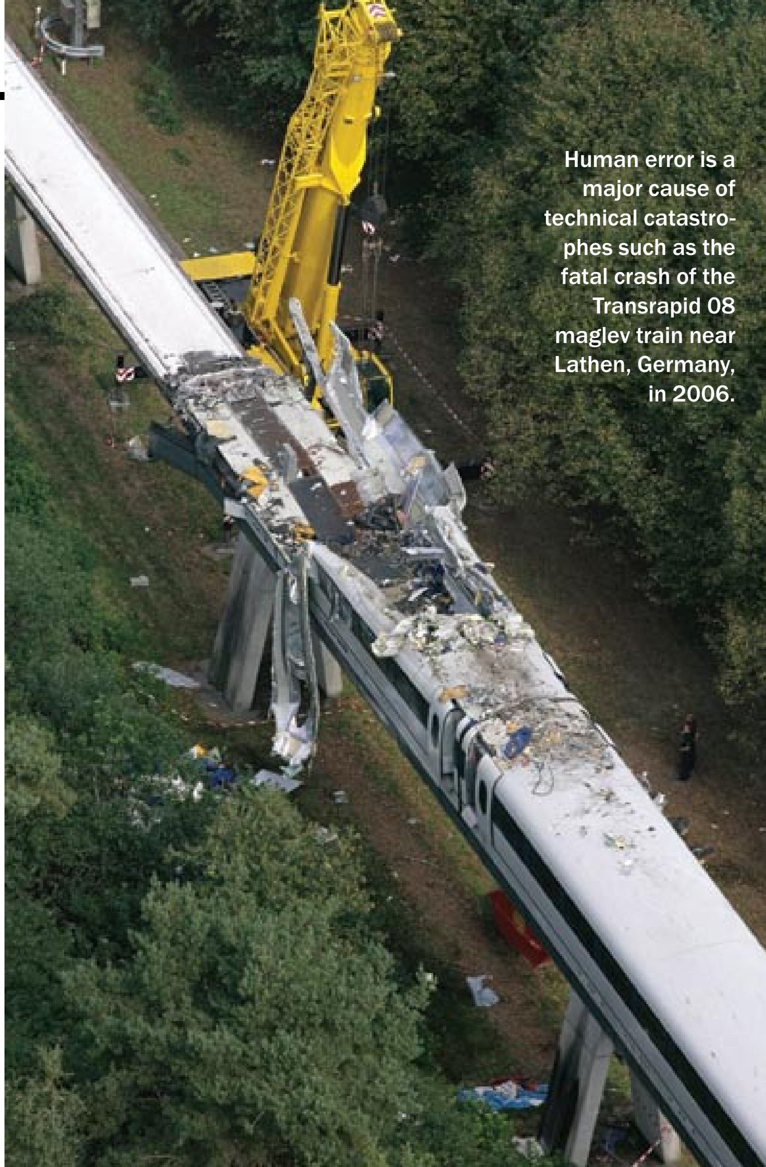


This map of the scalp shows the distribution of electrical potentials at the moment of a mistake. Goofs generate negative potentials in the middle of the head (*blue*) but not at the sides.



Just after a slipup, the brain's electrical potential suddenly becomes more negative (*red peak after response*), whereas correct actions (*blue and green lines*) do not cause big voltage drops.

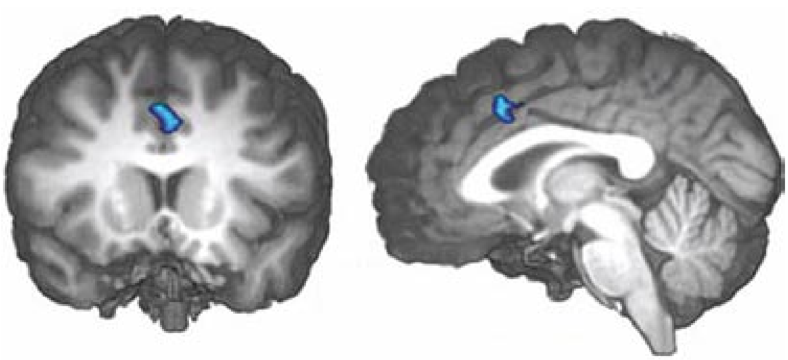
COURTESY OF MARKUS ULLSPERGER; SOURCE: "TRIAL-BY-TRIAL COUPLING OF CONCURRENT ELECTROENCEPHALOGRAM AND FUNCTIONAL MAGNETIC RESONANCE IMAGING IDENTIFIES THE DYNAMICS OF PERFORMANCE MONITORING," BY S. DEBENER ET AL., IN *JOURNAL OF NEUROSCIENCE*, VOL. 25, NO. 50; DECEMBER 14, 2005



Human error is a major cause of technical catastrophes such as the fatal crash of the Transrapid 08 maglev train near Lathen, Germany, in 2006.

al of that brain region. While these neurons were tapped, the patients did a task in which they had to choose one of two directions to move a joystick based on a visual cue that also specified a monetary reward: either nine or 15 cents. On the nine-cent trials, participants were supposed to change the direction in which they moved the joystick.

Similar to the responses of monkey neurons,



When a person makes an error, activity surges in the medial frontal cortex (*blue spots on brains*), the brain's primary error detector.

activity among the anterior cingulate neurons rose to the highest levels when the cue indicated a reduced reward along with a change in the direction of movement. In addition, the level of neuronal activity predicted whether a person would act as instructed or make an error. After surgical removal of those cells, the patients made more errors when they were cued to change their behavior in the face of a reduced payment. These neurons, therefore, seem to link information about rewards to behavior. After detecting discrepancies between actual and desired outcomes, the cells determine the corrective action needed to optimize reward.

But unless instructed to do so, animals do not generally alter their behavior after just one mishap. Rather they change strategies only after a pattern of failed attempts. The anterior cingulate also seems to work in this more practical fashion in arbitrating the response to errors. In a 2006 study experimental psychologists Stephen Kennerley and Matthew Rushworth and their colleagues at the University of Oxford taught rhesus monkeys to pull a lever to get food. After 25 trials, the researchers changed the rules, dispensing treats when the monkeys turned the lever instead of pulling it. The monkeys adapted and switched to turning the lever. After a while, the researchers changed the rules once more, and the monkeys again altered their behavior.

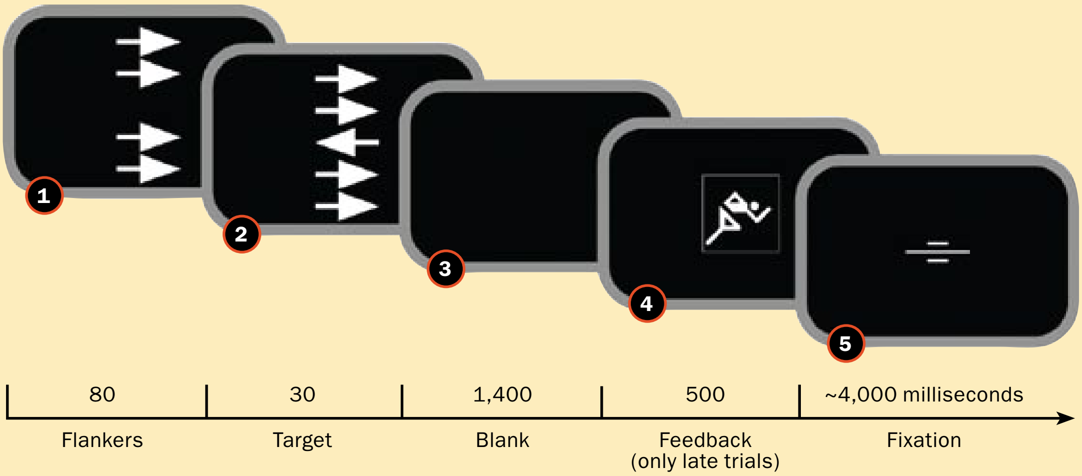
Each time the monkeys did not immediately switch actions, but did so only after a few false starts, using the previous four or five trials as a guide. After damage to the anterior cingulate, however, the animals lost this longer-term view and instead used only their most recent success or failure as a guide. Thus, the anterior cingulate seems to control an animal's ability to evaluate a short history of hits and misses as a guide to future decisions.

Chemical Incentive

Such evaluations may depend on dopamine, which conveys success signals in the brain. Neurophysiologist Wolfram Schultz, now at the University of Cambridge, and his colleagues have shown over the past 15 years that dopamine-producing nerve cells alter their activity when a reward is either greater or less than anticipated. When a monkey is rewarded unexpectedly, say, for a correct response, the cells become excited, releasing dopamine, whereas their activity drops when the monkey fails to get a treat after an error. And if dopamine quantity stably altered the connections between nerve cells, its differential

INGO WAGNER *dpa/Landov* (*train accident*); COURTESY OF MARKUS ULLSPERGER; SOURCE: DEBENER ET AL. (IBID.) (*brain scans*)

Arrow Detection



In a task used to study how people react to errors, a participant first sees a set of flanker, or decoy, arrows (*1*). Next, a central target arrow appears (*2*). The subject then presses a button to indicate the perceived direction of the target arrow, sometimes making a goof. If the response is too slow, a racing figure appears (*4*). After a delay (*5*), the participant repeats the sequence. The pattern of arrows may vary between trials.

COURTESY OF MARKUS ULLSPERGER; SOURCE: DEBENER ET AL. (IBID.)

release could thereby promote learning from successes and failures.

Indeed, changes in dopamine levels may help to explain how we learn from positive as well as negative reinforcement. Dopamine excites the brain's so-called Go pathway, which promotes a response while also inhibiting the action-suppressing "NoGo" pathway. Thus, bursts of dopamine resulting from positive reinforcement promote learning by both activating the Go channel and blocking NoGo. In contrast, dips in dopamine after negative outcomes should promote avoidance behavior by inactivating the Go pathway while releasing inhibition of NoGo.

In 2004 psychologist Michael J. Frank, then at the University of Colorado at Boulder, and his colleagues reported evidence for dopamine's influence on learning in a study of patients with Parkinson's disease, who produce too little of the neurotransmitter. Frank theorized that Parkinson's patients may have trouble generating the dopamine needed to learn from positive feedback but that their low dopamine levels may facilitate training based on negative feedback.

In the study the researchers displayed pairs of symbols on a computer screen and asked 19 healthy people and 30 Parkinson's patients to choose one symbol from each pair. The word "correct" appeared whenever a subject had chosen an arbitrarily correct symbol, whereas the word "incorrect" flashed after every "wrong" selection. (No symbol was invariably correct or incorrect.) One of them was deemed right 80 percent of the time, and another 20 percent. For other pairs, the probabilities were 70:30 and 60:40. The subjects were expected to learn from this feedback and thereby increase the number of correct choices in later test runs.

As expected, the healthy people learned to prefer the correct symbols and avoid the incorrect ones with about equal proficiency. Parkinson's patients, on the other hand, showed a stronger tendency to reject negative symbols than to select the positive ones—that is, they learned more from their errors than from their hits, showing that the lack of dopamine did bias their learning in the expected way. In addition, the patients' ability to learn from positive feedback outpaced that from negative feedback after they took medication that boosted brain levels of dopamine, underscoring the importance of dopamine in positive reinforcement.

Dopamine-based discrepancies in learning ability also appear within the healthy population. Last December, along with psychology graduate student Tilmann A. Klein and our colleagues, I

(The Author)

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Many mistakes are **surprisingly predictable**, foreshadowed by gradual changes in the activation of two brain networks.

showed that such variations are partly based on individual differences in a gene for the D2 dopamine receptor. A variant of this gene, called A1, results in up to a 30 percent reduction in the density of those receptors on nerve cell membranes.

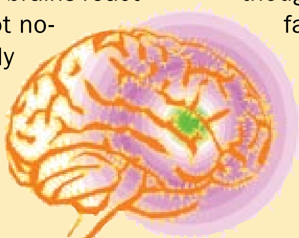
We asked 12 males with the A1 variant and 14 males who had the more common form of this gene to perform a symbol-based learning test like the one Frank used. We found that A1 carriers were less able to remember, and avoid, the negative symbols than were the participants who did not have this form of the gene. The A1 carriers also avoided the negative symbols less often than they picked the positive ones. Noncarriers learned about equally well from the good and bad symbols.

Thus, fewer D2 receptors may impair a person's ability to learn from mistakes or negative outcomes. (This molecular quirk is just one of many factors that influence such learning.) Accordingly, our fMRI results show that the medial frontal cortex of A1 carriers generates a weaker response to errors than it does in other people, suggesting that this brain area is one site at which dopamine exerts its effect on learning from negative feedback.

But if fewer D2 receptors leads to impaired avoidance learning, why do drugs that *boost* dopamine signaling also lead to such impairments in Parkinson's patients? In both scenarios, dopamine signaling may, in fact, be increased through other dopamine receptors; research indicates that A1 carriers produce an unusually large amount of dopamine, perhaps as a way to compensate for their lack of D2 receptors. Whatever the reason, insensitivity to unpleasant consequences may contribute to the slightly higher rates of obesity, compulsive gambling and addiction among A1 carriers than in the general population.

Subconscious Blunders

We are aware of many of our mistakes, but we also goof up without knowing it. Do our brains react the same way to errors we do not notice as to the ones of which we are painfully aware? The brain and body's responses to subconscious and conscious errors share some common features as well as some differences. In a 2001 study cognitive psychologist Sander Nieuwenhuis, now at the University of Leiden in the Netherlands, and his colleagues at the University of Amsterdam showed that the medial frontal cortex monitors subconscious errors just as it does conscious ones.



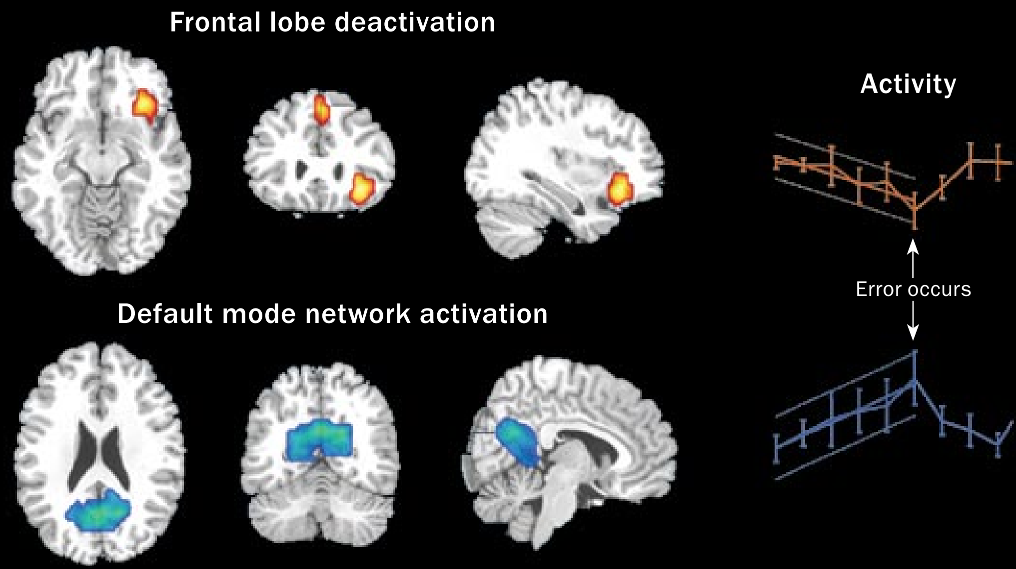
In this experiment, volunteers stared at a computer screen, and when a dot appeared on one side of the screen, they tried to direct their gaze to the *opposite* side. The subjects then pressed a key to indicate whether they thought they had responded correctly. Subjects failed to register about half of their own errors, being convinced in these cases that they had, in fact, looked in the right direction when they had not. The researchers found that the medial frontal cortex nonetheless registered every mistake.

Other parts of the brain do distinguish between conscious and unconscious errors, however. For instance, last year my colleagues and I showed that a brain region called the insula remains silent when we make subconscious slipups, although it does become alert during mistakes of which we are cognizant. And only conscious errors produce a bodily reaction, causing us to break out in a sweat. —*M.U.*

JUPITERIMAGES (*crumpled paper*); MATT KNANNLEIN *iStockphoto* (*brain*)

The Mind Unwinds

Changes in the brain may predict errors. About 30 seconds before a person makes a goof, two regions involved in task-related effort (*orange areas*) show a decline in metabolic activity (*red graph*). Meanwhile the default mode network (*blue areas*), which is usually dormant when someone is working on a task, becomes more active (*blue graph*), indicating mental relaxation.



Foreshadowing Faults

Although learning from mistakes may help us avoid future missteps, inexperience or inattention can still lead to errors. Many such goofs turn out to be predictable, however, foreshadowed by telltale changes in brain metabolism, according to research my team published in April in the *Proceedings of the National Academy of Sciences USA*.

Along with cognitive neuroscientist Tom Eichele of the University of Bergen in Norway and several colleagues, I asked 13 young adults to perform a flanker task while we monitored their brain activity using fMRI. Starting about 30 seconds before our subjects made an error, we found distinct but gradual changes in the activation of two brain networks.

One of the networks, called the default mode region, is usually more active when a person is at rest and quiets down when a person is engaged in a task. But before an error, the posterior part of this network—which includes the retrosplenial cortex, located near the center of the brain at the surface—became more active, indicating that the mind was relaxing. Meanwhile activity declined in areas of the frontal lobe that spring to life whenever a person is working hard at something, suggesting that the person was also becoming less engaged in the task at hand [*see box above*].

Our results show that errors are the product of gradual changes in the brain rather than unpredictable blips in brain activity. Such adjustments could be used to foretell errors, particularly those that occur during monotonous tasks. In the future, people might wear portable devices that monitor these brain states as a first step toward preventing mistakes where they are most likely to occur—and when they matter most. M

(Further Reading)

- **The Role of the Medial Frontal Cortex in Cognitive Control.** K. Richard Ridderinkhof, Markus Ullsperger, Eveline A. Crone and Sander Nieuwenhuis in *Science,* Vol. 306, pages 443–447; October 15, 2004.
- **By Carrot or by Stick: Cognitive Reinforcement Learning in Parkinsonism.** Michael J. Frank, Lauren C. Seeberger and Randall C. O'Reilly in *Science,* Vol. 306, pages 1940–1943; December 10, 2004.
- **Human Anterior Cingulate Neurons and the Integration of Monetary Reward with Motor Responses.** Ziv M. Williams et al. in *Nature Neuroscience,* Vol. 7, No. 12, pages 1370–1375; December 2004.
- **Neural Changes for Error Monitoring: Recent Findings and Theoretical Perspectives.** S. F. Taylor, E. R. Stern and W. J. Gehring in *The Neuroscientist,* Vol. 13, No. 2, pages 160–172; April 2007.
- **Genetically Determined Differences in Learning from Errors.** Tilmann A. Klein et al. in *Science,* Vol. 318, pages 1642–1645; December 7, 2007.
- **Prediction of Human Errors by Maladaptive Changes in Event-Related Brain Networks.** Tom Eichele et al. in *Proceedings of the National Academy of Sciences USA,* Vol. 105, No. 15, pages 6173–6178; April 22, 2008.

High-Aptitude Minds

Brain researchers are finding clues to the biological basis of **(brilliance)**

By Christian Hoppe and Jelena Stojanovic

Within hours of his demise in 1955, Albert Einstein's brain was salvaged, sliced into 240 pieces and stored in jars for safekeeping. Since then, researchers have weighed, measured and otherwise inspected these biological specimens of genius in hopes of uncovering clues to Einstein's spectacular intellect.

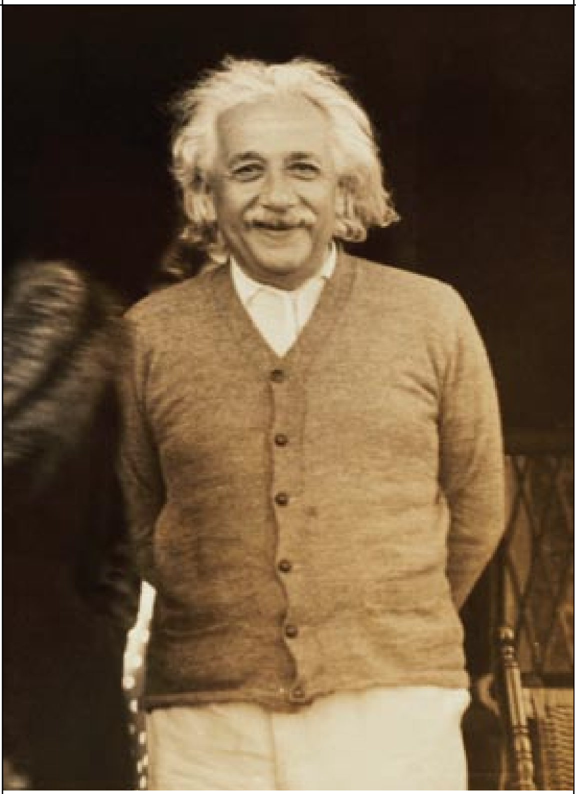
Their cerebral explorations are part of a century-long effort to uncover the neural basis of high intelligence or, in children, giftedness. Traditionally, 2 to 5 percent of kids qualify as gifted, with the top 2 percent scoring above 130 on an intelligence quotient (IQ) test. (The statistical average is 100. See the box on the opposite page.) A high IQ increases the probability of success in various academic areas. Children who are good at reading, writing or math also tend to be facile at the other two areas and to grow into adults who are skilled at diverse intellectual tasks [see "Solving the IQ Puzzle," by James R. Flynn; Scientific American Mind, October/November 2007].

Most studies show that smarter brains are typically bigger—at least in certain locations. Part of Einstein's parietal lobe (at the top of the head, behind the ears) was 15 percent wider than the same region was in 35 men of normal cognitive ability, according to a 1999 study by researchers at McMaster University in Ontario. This area is thought to be critical for visual and mathematical thinking. It is also within the constellation of brain regions fingered as important for superior cognition. These neural territories include parts of the parietal and frontal lobes as well as a structure called the anterior cingulate.

But the functional consequences of such enlargement are controversial. In 1883 English anthropologist and polymath Sir Francis Galton dubbed intelligence an inherited feature of an efficiently functioning central nervous system. Since then, neuroscientists have garnered support for this efficiency hypothesis using modern neuroimaging techniques. They found that the brains of brighter people use less energy to solve certain problems than those of people with lower aptitudes do.

In other cases, scientists have observed higher neuronal power consumption in individuals with superior mental capacities. Musical prodigies may also sport an unusually energetic brain [*see box on page 67*]. That flurry of activity may occur when a task is unusually challenging, some researchers speculate, whereas a gifted mind might be more efficient only when it is pondering a relatively painless puzzle.

Despite the quest to unravel the roots of high IQ, researchers say that people often overestimate the significance of intellectual ability [see "Coaching the Gifted Child," by Christian Fischer, on page 68]. Studies show that practice and perseverance contribute more to accomplishment than being smart does.



FAST FACTS

All in the Head

1» Smarter brains tend to be bigger—at least in certain locations. Researchers have fingered parts of the parietal and frontal lobes as well as a structure called the anterior cingulate as important for superior cognition.

2» Some studies suggest that the brains of brighter people use less energy to solve certain problems than those of people with lower aptitudes do. But under certain circumstances, scientists have also observed higher neuronal power consumption in individuals with superior mental capacities.

3» People often overestimate the importance of intellectual ability. Practice and perseverance contribute more to accomplishment than being smart does.

PRECEDING PAGES: AGE FOTOSTOCK (*man and chalkboard*); 3D CLINIC/GETTY IMAGES (*neuron overlay*); THIS PAGE: DEBORAH BETZ COLLECTION/CORBIS (*Einstein*)

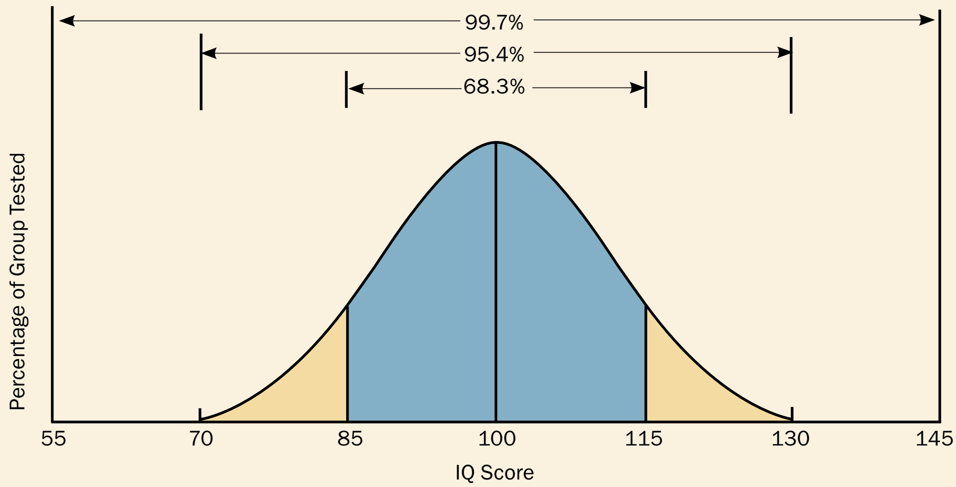
All else equal, **bigger brains** are smarter: brain volume accounts for about 16 percent of the variance in IQ.

Flavors of Smart

Objective intelligence tests are the best way to identify high intelligence. The bell curve below represents the distribution of scores on such exams. In addition to revealing how bright a child is, IQ tests generate an individual aptitude profile, which identifies a child's particular strengths and weaknesses. Educators can use those profiles to tailor gifted programs or projects to each child.

—*Christian Fischer*

Percentages of People with IQ Scores within These Ranges



Bright: 115+, or one in six (84th percentile)

Gifted: 130+, or 1 in 50 (98th percentile)

Highly gifted: 145+, or 1 in 1,000 (99.9th percentile)

Size Matters

In humans, brain size correlates, albeit somewhat weakly, with intelligence, at least when researchers control for a person's sex (male brains are bigger) and age (older brains are smaller). Many modern studies have linked a larger brain, as measured by magnetic resonance imaging, to higher intellect, with total brain volume accounting for about 16 percent of the variance in IQ. But, as Einstein's brain illustrates, the size of some brain areas may matter for intelligence much more than that of others does.

In 2004 psychologist Richard J. Haier of the University of California, Irvine, and his colleagues reported evidence to support the notion that discrete brain regions mediate scholarly aptitude. Studying the brains of 47 adults, Haier's team found an association between the amount of gray matter (tissue containing the cell bodies of neurons) and higher IQ in 10 discrete regions, including three in the frontal lobe and two in the parietal lobe just behind it. Other scientists have also seen more white matter, which is made up of nerve axons (or fibers), in these same regions among people with higher IQs. The results point to a widely distributed—but discrete—neural basis of intelligence.

The neural hubs of general intelligence may change with age. Among the younger adults in Haier's study—his subjects ranged in age from 18 to 84—IQ correlated with the size of brain regions near a central structure called the cingulate, which participates in various cognitive and emotional tasks. That result jibed with the findings, published a year earlier, of pediatric neurologist Marko Wilke, then at Cincinnati Children's Hospital Medical Center, and his colleagues. In its survey of 146 children ages five to 18 with a range of IQs, the Cincinnati group discovered a strong connection between IQ and gray matter volume in the cingulate but not in any other brain structure the researchers examined.

Scientists have identified other shifting neural patterns that could signal high IQ. In a 2006 study child psychiatrist Philip Shaw of the National Institute of Mental Health and his colleagues scanned the brains of 307 children of varying intelligence multiple times to determine the thickness of their cerebral cortex, the brain's exterior part. They discovered that academic prodigies younger than eight had an unusually thin cerebral cortex, which then thickened rapidly so that by late childhood it was chunkier than that of less clever kids. Consistent with other studies, that pattern was particularly pronounced in the frontal brain regions that govern rational thought processes.

The brain structures responsible for high IQ may vary by sex as well as by age. A recent study by Haier, for example, suggests that men and women achieve similar results on IQ tests with the aid of different brain regions. Thus, more than one type of brain architecture may underlie high aptitude.

Low Effort Required

Meanwhile researchers are debating the functional consequences of these structural findings. Over the years brain scientists have garnered evidence supporting the idea that high intelligence stems from faster information processing in the brain. Underlying such speed, some psychologists argue, is unusually efficient neural circuitry in the brains of gifted individuals.

Experimental psychologist Werner Krause, formerly at the University of Jena in Germany, for example, has proposed that the highly gifted solve puzzles more elegantly than other people do: they rapidly identify the key information in them and the best way to solve them. Such people thereby make optimal use of the brain's limited working memory, the short-term buffer that holds items just long enough for the mind to process them.

Starting in the late 1980s, Haier and his colleagues have gathered data that buttress this so-called efficiency hypothesis. The researchers used positron-emission tomography, which measures glucose metabolism of cells, to scan the brains of eight young men while they performed a nonverbal abstract reasoning task for half an hour. They found that the better an individual's performance

(In one theory, **high intelligence** stems from efficient neural machinery and rapid data processing in the brain.)

Right over Left

Genius in areas such as math, music and art is accompanied by extensive use of the right hemisphere of the brain over the left. In the 1980s Harvard University neurologists Norman Geschwind and Albert Galaburda were intrigued by the fact that many such mathematically, musically and artistically gifted people are also left-handed or ambidextrous and are more likely to have left-hemisphere deficits, such as stuttering or dyslexia. Geschwind and Galaburda suggested that such a right-hemisphere preeminence could result from higher-than-average testosterone levels in the womb: some studies indicate that testosterone can impede the development of the brain's left hemisphere and thus, to compensate, might facilitate that of the right.

Of course, male fetuses are typically exposed to higher testosterone doses than female ones are, providing a possible explanation for the preponderance of male math prodigies and of males with language disorders. This hormonal account of the origins of genius—and pathology—remains controversial, however. *—C.H. and J.S.*

MOHAMED SADATH *iStockphoto*

SMART SIBLINGS: Lea Schlierfstein (*left*), 10, is a self-described bookworm. She is also a member of a Chinese Club. Nico Schlierfstein (*right*), eight, has already skipped a grade. His favorite pursuits are math, religion and sports.

COURTESY OF MARKUS SCHLIERFSTEIN

on the task, the lower the metabolic rate in widespread areas of the brain, supporting the notion that efficient neural processing may underlie brilliance. And in the 1990s the same group observed the flip side of this phenomenon: higher glucose metabolism in the brains of a small group of subjects who had below-average IQs, suggesting that slower minds operate less economically.

More recently, in 2004 psychologist Aljoscha Neubauer of the University of Graz in Austria and his colleagues linked aptitude to diminished cortical activity after learning. The researchers used electroencephalography (EEG), a technique that detects electrical brain activity at precise time points using an array of electrodes affixed to the scalp, to monitor the brains of 27 individuals while they took two reasoning tests, one of them given before test-related training and the other after it. During the second test, frontal brain regions—many of which are involved in higher-order cognitive skills—were less active in the more intelligent individuals than in the less astute subjects. In fact, the higher a subject's mental ability, the bigger the dip in cortical activation between the pretraining and posttraining tests, suggesting that the brains of brighter individuals streamline the processing of new information faster than those of their less intelligent counterparts do.

The cerebrums of smart kids may also be more efficient at rest, according to a 2006 study by psychologist Joel Alexander of Western Oregon University and his colleagues. Using EEG, Alexander's team found that resting eight- to 12-hertz alpha brain waves were significantly more powerful in 30 adolescents of average ability than they were in 30 gifted adolescents, whose alpha-wave signal resembled those of older, college-age students. The results suggest that gifted kids' brains use relatively little energy while idle and in this respect resemble more developmentally advanced human brains.

Some researchers speculate that greater energy efficiency in the brains of gifted individuals could arise from increased gray matter, which might provide more resources for data processing, lessening the strain on the brain. But others, such as economist Edward Miller, formerly of the University of New Orleans, have proposed that the efficiency boost could also result from thicker myelin, the substance that insulates nerves and ensures rapid conduction of nerve signals. No one knows if the brains of the quick-witted generally contain more myelin, although Einstein's might have. Scientists probing Einstein's brain in the 1980s discovered an unusual number of glia, the cells that make up myelin, relative to neurons in one area of his parietal cortex.

Hardworking Minds

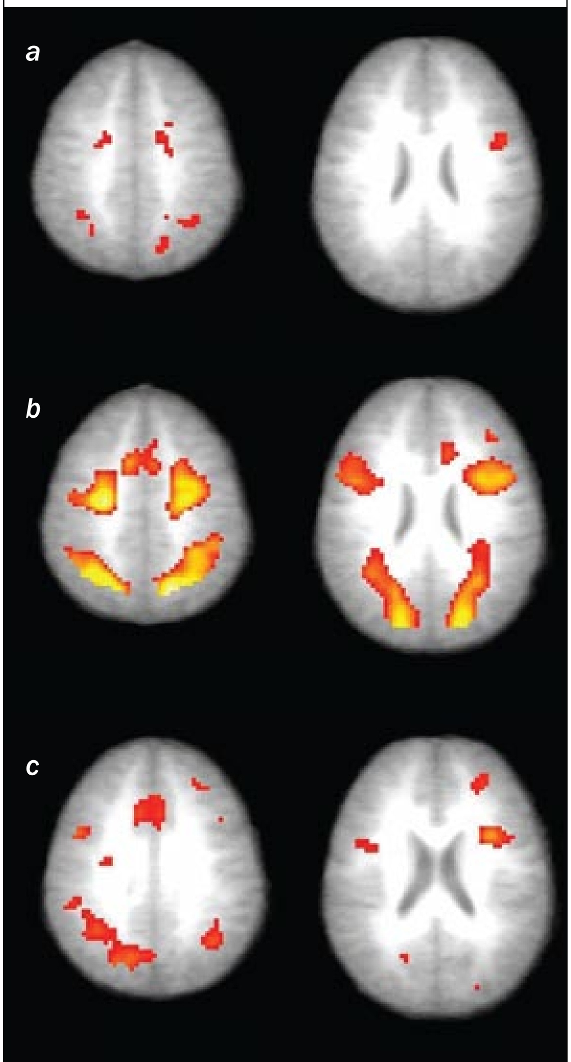
And yet gifted brains are not always in a state of relative calm. In some situations, they appear to be *more* energetic, not less, than those of people of more ordinary intellect. What is more, the energy-gobbling brain areas roughly correspond to those boasting more gray matter, suggesting that the gifted may simply be endowed with more brainpower in this intelligence network.

In a 2003 trial psychologist Jeremy Gray, then at Washington University in St. Louis, and his colleagues scanned the brains of 48 individuals

(The Authors)

Psychologists CHRISTIAN HOPPE and JELENA STOJANOVIC study the neuronal basis of intelligence at the University Clinic for Epileptology in Bonn, Germany.

Some experiments suggest a **bright brain** is a hardworking one, whereas others indicate it is one that can relax.



GIFTED BRAINS: Scientists found higher levels of brain activity in mathematically gifted boys (*b*) than in boys of normal intelligence (*a*) when they performed a mental rotation task. Some brain regions (*c*) were uniquely activated in the gifted boys.

SOURCE: "MATHEMATICALLY GIFTED MALE ADOLESCENTS ACTIVATE A UNIQUE BRAIN NETWORK DURING MENTAL ROTATION," BY MICHAEL W. O'BOYLE, ROSS CUNNINGTON, TIMOTHY J. SILK, DAVID VAUGHAN, GRAEME JACKSON, ARI SYNGENIOTIS AND GARY F. EGAN, IN *COGNITIVE BRAIN RESEARCH*, VOL. 25, NO. 2; OCTOBER 2005 © 2005 BY PERMISSION OF ELSEVIER

using functional MRI, which detects neural activity by tracking the flow of oxygenated blood in brain tissue, while the subjects completed hard tasks that taxed working memory. The researchers saw higher levels of activity in prefrontal and parietal brain regions in the participants who had received high scores on an intelligence test, as compared with low scorers.

In a 2005 study a team led by neuroscientist Michael O'Boyle of Texas Tech University found a similar brain activity pattern in young male math geniuses. The researchers used fMRI to map the brains of mathematically gifted adolescents while they mentally rotated objects to try to match them to a target item. Compared with adolescent boys of average math ability, the brains of the mathematically talented boys were more metabolically active—and that activity was concentrated in the parietal lobes, the frontal cortex and the anterior cingulate [*see illustration at left*].

A year later biologist Kun Ho Lee of Seoul National University in Korea similarly linked elevated activity in a frontoparietal neural network to superior intellect. Lee and his co-workers measured brain activity in 18 gifted adolescents and 18 less intelligent young people while they performed difficult reasoning tasks. These tasks, once again, excited activity in areas of the frontal and parietal lobes, including the anterior cingulate, and this neural commotion was significantly more intense in the gifted individuals' brains.

No one is sure why some experiments indicate that a bright brain is a hardworking one, whereas others suggest it is one that can afford to relax. Some, such as Haier—who has found higher brain metabolic rates in more astute individuals in some of his studies but not in others—speculate one reason could relate to the difficulty of the tasks. When a problem is very complex, even a gifted person's brain has to work to solve it. The brain's relatively high metabolic rate in this instance might reflect greater engagement with the task. If that task was out of reach for someone of average intellect, that person's brain might be relatively inactive because of an inability to tackle the problem. And yet a bright individual's brain might nonetheless solve a less difficult problem efficiently and with little effort as compared with someone who has a lower IQ.

Perfection from Practice

Whatever the neurological roots of genius, being brilliant only increases the probability of success; it does not ensure accomplishment in any endeavor. Even for academic achievement, IQ is not as important as self-discipline and a willingness to work hard.

University of Pennsylvania psychologists Angela Duckworth and Martin Seligman examined final grades of 164 eighth-grade students, along with their admission to (or rejection from) a prestigious high school. By such measures, the researchers determined that scholarly success was more than twice as dependent on assessments of self-discipline as on IQ. What is more, they reported in 2005, students with more self-disci-

Musical Minds

While some scientists probe the neural correlates of intellectual proficiency [*see main article*], others are investigating the biological underpinnings of musical talent. Like the quick-witted, highly trained musicians also seem to have distinctive brain anatomy and neural activity patterns as compared with those who lack a bent for music.

In 2002 neuroscientist Vanessa Sluming and her team at the University of Liverpool in England demonstrated by MRI a higher density of gray matter—that is, nerve cell bodies—in the brain's speech region, Broca's area, in orchestra musicians relative to a control group. In musicians, Broca's area is thought to mediate the visual skills and sequencing of fast motor actions required when sight-reading a piece. A year later psychiatrist Christian Gaser of the University of Jena in Germany and neurologist Gottfried Schlaug of Harvard Medical School also reported gray matter volume differences in motor, auditory and visuospatial brain regions in professional keyboard players as compared with amateur musicians and nonmusicians.

In 2007 Sluming and her colleagues reported functional peculiarities in musicians' brains. In particular, their findings suggest that the enlargement of Broca's area endows musicians with superior spatial skills. Not only were musicians especially good at a spatial task involving rotating objects in three-dimensional space, but performing these mental rotations also elicited a flurry of activity in Broca's area, as assessed by functional MRI, whereas no comparable activity occurred in the brains of nonmusicians.

While listening to music, the brains of musical prodigies may be unusually active in other regions, too. In 1998 neuroscientist Christo Pantev of the University of Münster in Germany and his colleagues reported that musicians exhibited approximately 25 percent more cortical activity when listening to piano tones than nonmusicians did, as measured by magnetoencephalography, which registers magnetic field potentials from the scalp. This extra neural commotion appears to occur only in response to music—which musicians may be analyzing in greater depth than the average person does—and not to spoken text, according to a 2001 study by psychologist Joydeep Bhattacharya, then at the Austrian Academy of Sciences in Vienna, and his colleagues.

Many researchers believe that the bulk of these structural and functional brain differences result from lots of practice. After all, the most skilled musicians begin playing before the age of six, providing plenty of time for musical exercises to mold the developing brain.

—C.H. and J.S.

PIANO PRODIGY: Pianist Lang Lang has performed in public since the age of five and won his first international prize at 11.

WANG MUMU *Imaginechina*/AP Photo

pline—a willingness to sacrifice short-term pleasure for long-term gain—were more likely than those lacking this skill to improve their grades during the school year. A high IQ, on the other hand, did not predict a climb in grades.

A 2007 study by Neubauer's team of 90 adult tournament chess players similarly shows that practice and experience are more important to expertise than general intelligence is, although the latter is related to chess-playing ability. Even Einstein's spectacular success as a mathematician and a physicist cannot be attributed to intellectual prowess alone. His education, dedication to the problem of relativity, willingness to take risks, and support from family and friends probably helped to push him ahead of any contemporaries with comparable cognitive gifts. M

(Further Reading)

- **Bright Spots: Correlations of Gray Matter Volume with IQ in a Normal Pediatric Population.** Marko Wilke, Jin-Hun Sohn, Anna M. Weber Byars and Scott K. Holland in *Neuroimage,* Vol. 20, No. 1, pages 202–215; September 2003.
- **Self-Discipline Outdoes IQ in Predicting Academic Performance of Adolescents.** A. L. Duckworth and M. E. Seligman in *Psychological Science,* Vol. 16, No. 12, pages 939–944; December 2005.
- **Intellectual Ability and Cortical Development in Children and Adolescents.** Philip Shaw et al. in *Nature,* Vol. 440, pages 676–679; March 30, 2006.
- **The Expert Mind.** Philip E. Ross in *Scientific American,* Vol. 295, No. 2, pages 64–71; August 2006.
- **Sensitivity of Alpha Band ERD to Individual Differences in Cognition.** A. C. Neubauer, A. Fink and R. H. Grabner in *Progress in Brain Research,* Vol. 159, pages 167–178; 2006.
- **The Parieto-Frontal Integration Theory (P-FIT) of Intelligence: Converging Neuroimaging Evidence.** Rex E. Jung and Richard J. Haier in *Behavioral and Brain Sciences,* Vol. 30, No. 2, pages 135–154; April 2007.

Coaching the Gifted Child

Enrichment activities can provide **mental stimulation** for very bright kids

By Christian Fischer

Contrary to what many people believe, highly intelligent children are not necessarily destined for academic success. In fact, so-called gifted students may fail to do well because they are unusually smart. Ensuring that a gifted child reaches his or her potential requires an understanding of what can go wrong and how to satisfy the unusual learning requirements of extremely bright young people.

One common problem gifted kids face is that they, and those around them, place too much importance on being smart. Such an emphasis can breed a belief that bright people do not have to work hard to do well. Although smart kids may not need to work hard in the lower grades, when the work is easy, they may struggle and perform poorly when the work gets harder because they do not make the effort to learn. In some cases, they may not know how to study, having never done it before. In others, they simply cannot accept the fact that some tasks require effort [see "The Secret to Raising Smart Kids," by Carol S. Dweck; Scientific American Mind, December 2007/January 2008].

If the scholastic achievement of highly intelligent children remains below average for an extended period, many teachers will fail to recognize their potential. As a result, such students may not get the encouragement they need, further depressing their desire to learn. They may fall far behind in their schoolwork and even develop behavior problems. Boys may turn aggressive or become class clowns. Girls often develop performance anxiety and psychosomatic symptoms such as stomachaches [see "Watching Prodigies for the Dark Side," by Marie-Noëlle Ganry-Tardy; Scientific American Mind, April 2005].

One way to avoid such difficulties is to recognize that IQ is just one ingredient among many in the recipe for success. Children thrive or struggle in school for a host of reasons apart from IQ, according to psychologist Franz Mönks of the University of Nijmegen in the Netherlands. These include motivation and persistence, social competence, and the support of family, educators and friends. Emphasizing the importance of persistence and hard work, for example, will help a child avoid the laziness trap. Gifted children also need intellectual challenges—to teach them how to work hard.

Acceleration or Enrichment?

Highly gifted children solve the most varied thought problems faster and more thoroughly than those with more average aptitudes do. Because these children speed through the regular curriculum for their grade, they need additional intellectual stimulation while they wait for the

HOLLOWAY Getty Images

rest of the kids to learn the basics. Two central approaches are used to satisfy the educational needs of such children: acceleration and enrichment. Acceleration means studying material that is part of the standard curriculum for older students. Enrichment involves learning information that falls outside the usual curriculum—say, investigating a topic in greater depth or finding out about new topics.

the required material faster. Gifted kids might get the stimulation they require by, say, joining a chess club, a math or debate team, or another enrichment activity that engages their intellect. Another common technique is to enable a child to embark on an independent project or experiment under the guidance of a mentor.

The independent project approach has met with success in varied educational settings. In the "revolving door" model developed by educational psychologists Joseph Renzulli and Sally Reis of the University of Connecticut, a broad swath of above-average elementary school students—those who score in the top 15 to 25 percent on standardized tests—leave their regular classrooms for several hours to work individually on projects of their own choosing.

(When a child skips a grade, that child **may feel inferior** to his or her classmates in every nonacademic realm.)

One way to accelerate children is through early schooling, a term that refers to expanding educational opportunities to children younger than five years. Such schooling may be very beneficial: one extraordinarily talented little boy I met had learned to read fluently even before entering school.

A child might also skip one or more grades as a way of accelerating in school. But being with older children for the entire school day—and perhaps for grade-based extracurricular activities such as sports—can make a child feel inferior in every realm outside of academics. One very bright fourth-grader who had skipped two grades remained far ahead of his classmates intellectually, but as his classmates reached puberty, his social and other shortcomings became painfully apparent. To compensate, he began to brag about how smart he was, and his classmates responded by calling him "crazy" and "show-off" and by totally excluding him from their social life.

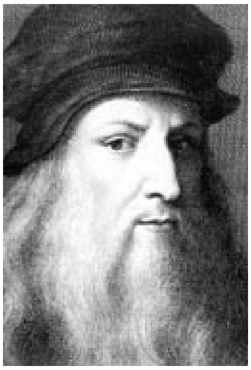
Because of such problems, most highly gifted children are better off if they largely remain in the grade with other children their age. Alternatively, mixed-age classes such as those found at Montessori schools prevent precocious students from leaving their regular class completely and yet may enable some acceleration for younger students. In some cases, gifted kids might be given the opportunity to, say, take an accelerated class in a subject that interests them while remaining in their regular classroom for other subjects.

When acceleration is not an option, or not a good one, enrichment can be. After all, school is not a race but an adventure in learning. As such, the goal is not finishing first but absorbing as much knowledge as possible in the time allotted. Thus, providing opportunities for a child to study topics outside the regular curriculum can be at least as valuable as pushing him or her through

In 2003 my colleagues at the University of Münster and I founded the Forder-Förder (challenge-encourage) program, in which kids in grades two through seven spend two hours per week outside their regular classroom studying a subject that interests them. So far 346 kids have completed the program, which usually culminates in a presentation to a teacher and classmates. One second-grade participant produced a documentary about Wilhelm Conrad Röntgen—the physicist who discovered x-ray radiation—that was later shown at the Röntgen Museum in Remscheid, Germany. Other children have put together presentations on bionics, black holes, female pirates, and the life of Queen Luise of Prussia. Gifted kids typically choose to learn about complex topics that are too advanced for most kids their age.

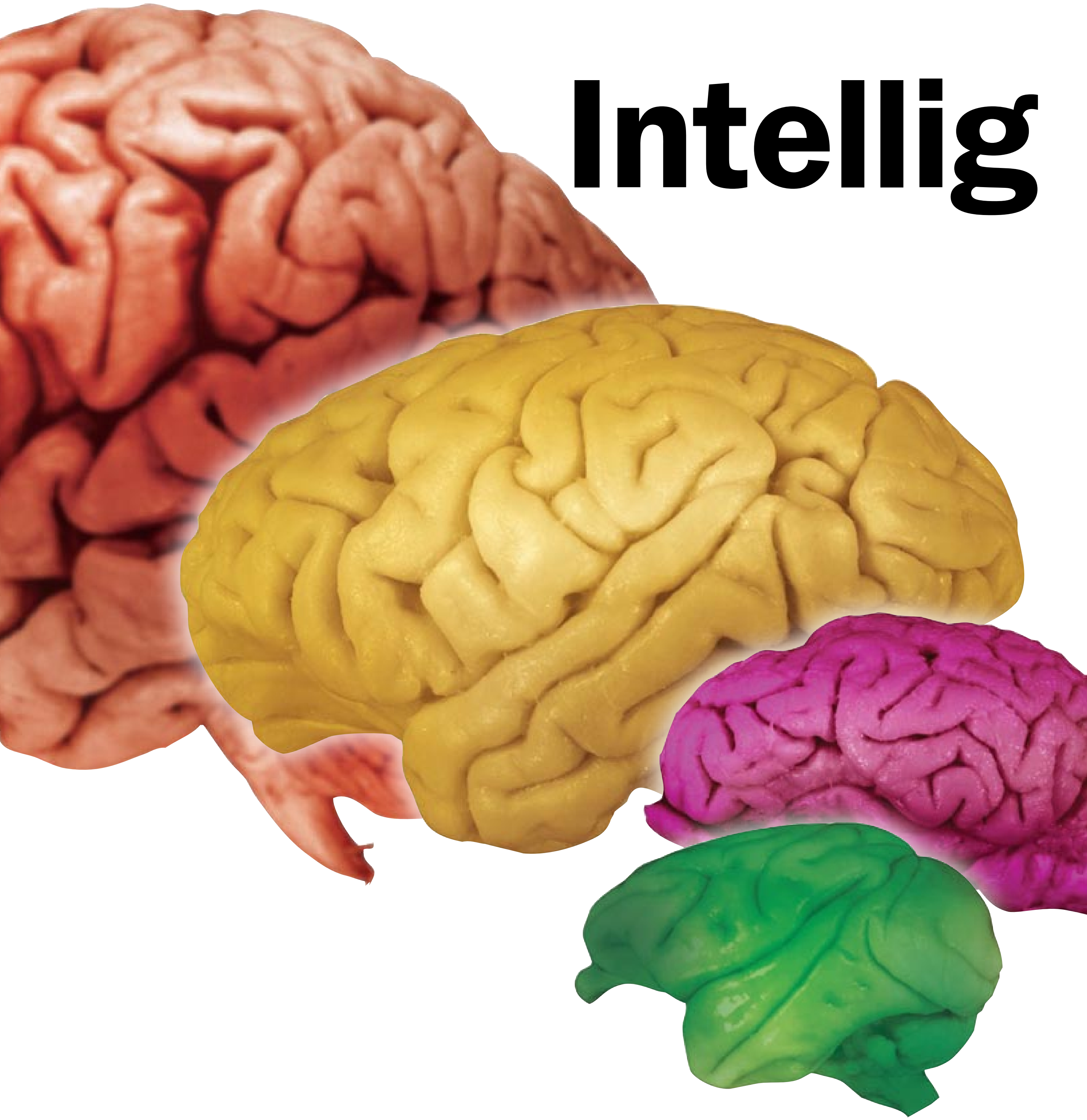
The programs and suggestions described here demonstrate that what highly gifted students need most are good mentors to serve as guides as they navigate complex subject matter. This specialized learning process benefits not only the gifted children but others as well: when the participating students share the fruits of their labors, the rest of their class also reaps the reward of learning something new. **M**

CHRISTIAN FISCHER is an educator, a psychologist and director of the International Center for the Study of Giftedness at the University of Münster in Germany and the University of Nijmegen in the Netherlands.



Highly gifted individuals sometimes display surprising weaknesses. Leonardo da Vinci, for example, was a poor speller. Gifted children may be sensitive to logical contradictions in spelling. Their motor skills may also develop relatively slowly, making their penmanship difficult to read.

Intellig



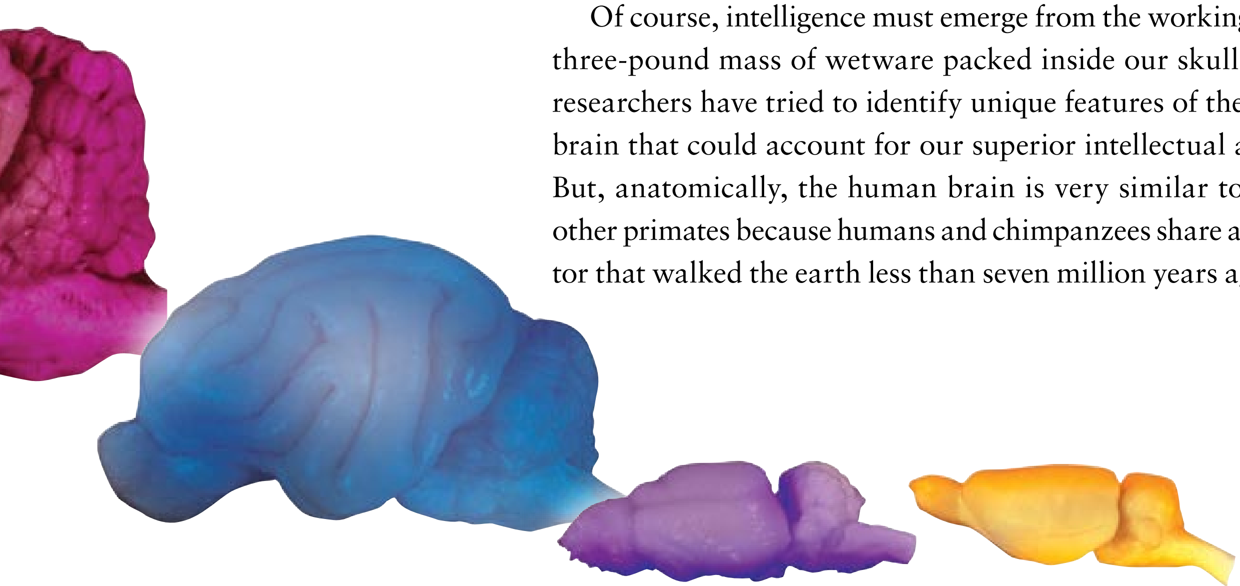
ence Evolved

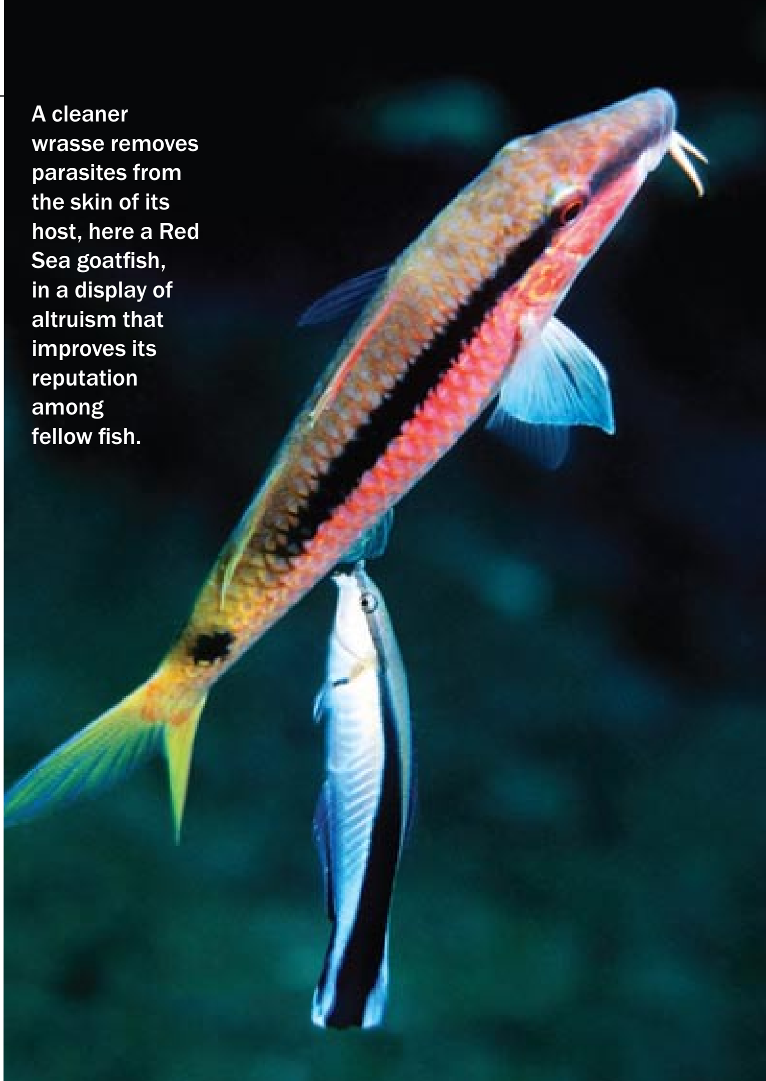
What makes people smarter than other animals? Human intelligence seems to have emerged from subtle refinements in brain architecture rather than from large-scale alterations

By Ursula Dicke and Gerhard Roth

As far as we know, no dog can compose music, no dolphin can speak in rhymes, and no parrot can solve equations with two unknowns. Only humans can perform such intellectual feats, presumably because we are smarter than all other animal species—at least by our own definition of intelligence.

Of course, intelligence must emerge from the workings of the three-pound mass of wetware packed inside our skulls. Thus, researchers have tried to identify unique features of the human brain that could account for our superior intellectual abilities. But, anatomically, the human brain is very similar to that of other primates because humans and chimpanzees share an ancestor that walked the earth less than seven million years ago.





A cleaner wrasse removes parasites from the skin of its host, here a Red Sea goatfish, in a display of altruism that improves its reputation among fellow fish.

Accordingly, the human brain contains no highly conspicuous characteristics that might account for the species' cleverness. For instance, scientists have failed to find a correlation between absolute or relative brain size and acumen among humans and other animal species. Neither have they been able to discern a parallel between wits and the size or existence of specific regions of the brain, excepting perhaps Broca's area, which governs speech in people. The lack of an obvious structural correlate to human intellect jibes with the idea that our intelligence may not be wholly unique: studies are revealing that chimps, among various other species, possess a diversity of humanlike social and cognitive skills.

Nevertheless, researchers have found some microscopic clues to humanity's aptitude. We have more neurons in our brain's cerebral cortex (its outermost layer) than other mammals do. The insulation around nerves in the human brain is also thicker than that of other species, enabling the nerves to conduct signals more rapidly. Such biological subtleties, along with behavioral ones, suggest that human intelligence is best likened to an upgrade of the cognitive capacities of nonhuman primates rather than an exceptionally advanced form of cognition.

Smart Species

Because animals cannot read or speak, their aptitude is difficult to discern, much less measure. Thus, comparative psychologists have invented behavior-based tests to assess birds' and mammals' abilities to learn and remember, to comprehend numbers and to solve practical problems. Animals of various stripes—but especially nonhuman primates—often earn high marks on such action-oriented IQ tests. During World War I, German psychologist Wolfgang Köhler, for example, showed that chimpanzees, when confronted with fruit hanging from a high ceiling, devised an ingenious way to get it: they stacked boxes to stand on to reach the fruit. They also constructed long sticks to reach food outside their enclosure. Researchers now know that great apes have a sophisticated understanding of tool use and construction.

Psychologists have used such behavioral tests to illuminate similar cognitive feats in other mammals as well as in birds. Pigeons can discriminate between male and female faces and among paintings by different artists; they can also group pictures into categories such as trees, selecting those belonging to a category by pecking with their beaks, an action that often brings a food reward. Crows have intellectual capacities that are overturning conventional wisdom about the brain [*see box on page 74*].

Behavioral ecologists, on the other hand, prefer to judge animals on their street smarts—that is, their ability to solve problems relevant to survival in their natural habitats—rather than on their test-taking talents. In this view, intelligence

FAST FACTS

The Emergence of Acumen

1» The human brain lacks conspicuous characteristics—such as relative or absolute size—that might account for humans' superior intellect.

2» Researchers have found some clues to humanity's aptitude on a smaller scale, such as more neurons in our brain's outermost layer.

3» Human intelligence may be best likened to an upgrade of the cognitive capacities of nonhuman primates rather than an exceptionally advanced form of cognition.

PRECEDING PAGES: REPRODUCED WITH PERMISSION: IMAGES BY WALLY WELKER (UNIVERSITY OF WISCONSIN–MADISON) FROM WWW.BRAINMUSEUM.ORG (SUPPORTED BY THE U.S. NATIONAL SCIENCE FOUNDATION, GRANT NO. 0131028); THIS PAGE: GEORGETTE DOUWMA *SPL/Photo Researchers, Inc.*

Intellect seems to have emerged independently in birds and mammals and also in cetaceans and primates.

is a cluster of capabilities that evolved in response to particular environments. Some scientists have further proposed that mental or behavioral flexibility, the ability to come up with novel solutions to problems, is another good measure of animal intellect. Among birds, green herons occasionally throw an object in the water to lure curious fish—a trick that, ornithologists have observed, has been reinvented by groups of these animals living in distant locales. Even fish display remarkable practical intelligence, such as the use of tools, in the wild. Cichlid fish, for instance, use leaves as "baby carriages" for their egg masses.

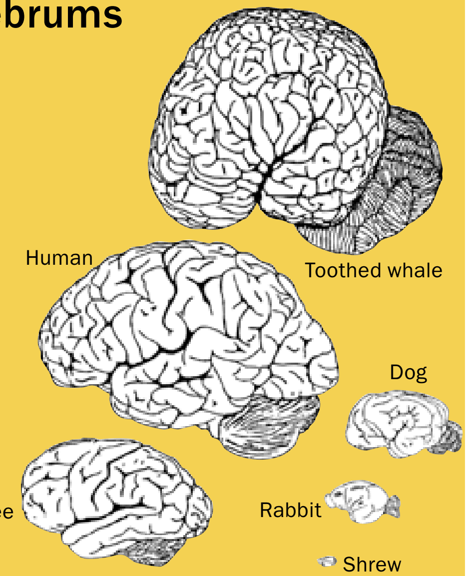
Animals also can display humanlike social intelligence. Monkeys engage in deception, for example; dolphins have been known to care for another injured pod member (displaying empathy), and a whale or porpoise may recognize itself in the mirror. Even some fish exhibit subtle kinds of social skills. Behavioral ecologist Redouan Bshary of the University of Neuchâtel in Switzerland and his colleagues described one such case in a 2006 paper. Bony fish such as the so-called cleaner wrasse (*Labroides dimidiatus*) [*see illustration on opposite page*] cooperate and remove parasites from the skin of other fish or feed on their mucus. Bshary's team found that bystander fish spent more time next to cleaners the bystanders had observed being cooperative than to other fish. Humans, the authors note, tend to notice altruistic behavior and are more willing to help do-gooders whom they have observed doing favors for others. Similarly, cleaner wrasses observe and evaluate the behavior of other finned ocean denizens and are more willing to help fish that they have seen assisting third parties.

From such studies, scientists have constructed evolutionary hierarchies of intelligence. Primates and cetaceans (whales, dolphins and porpoises) are considered the smartest mammals. Among primates, humans and apes are considered cleverer than monkeys, and monkeys more so than prosimians. Of the apes, chimpanzees and bonobos rank above gibbons, orangutans and gorillas. Dolphins and sperm whales are supposedly smarter than nonpredatory baleen whales such as blue whales. Among birds, scientists consider parrots, owls and corvids (crows and ravens) the brightest. Such a pecking order argues against the idea that intelligence evolved along a single path, culminating in human acumen. Instead intellect seems to have emerged independently in

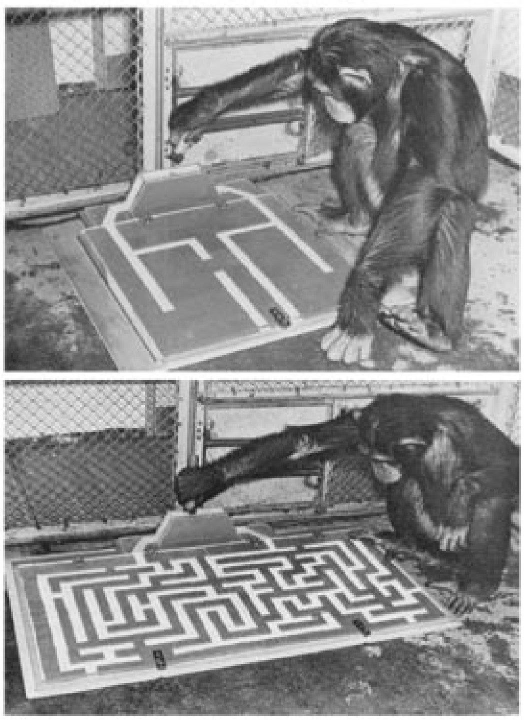
Sizing Up Cerebrums

Brain weight (grams)

Sperm whale	9,000
African elephant	4,200
Bottlenose dolphin	1,350
Human	1,350
Horse	510
Gorilla	500
Ox	490
Chimpanzee	380
Lion	260
Rhesus monkey	88
Dog	64
Cat	25
Rat	2
Mouse	0.3



SOURCE: "Brain Sizes, Surfaces, and Neuronal Sizes of the Cortex Cerebri: A Stereological Investigation of Man and His Variability and a Comparison with Some Mammals (Primates, Whales, Marsupials, Insectivores, and One Elephant)," by H. Haug, in American Journal of Anatomy, *Vol. 180, No. 2, October 1987*



A chimp at the University of Münster in Germany devised successful strategies for solving a simple maze (*top*) and a complex maze (*bottom*).

COURTESY OF GERHARD ROTH (*brain volumes*); SOURCE: "MANIPULIERFAEHIGKEIT UND KOMPLIKATION VON HANDLUNGSKETTEN BEI MENSCHENAFFEN," BY BERNHARD RENSCH, IN *HANDGEBRAUCH UND VERSTAENDIGUNG BEI AFFEN UND FRUEHMENSCHEN*, EDITED BY BERNHARD RENSCH, HANS HUBER, 1968 (*chimp*)

Clever Crows

Some birds display mental powers comparable to those of nonhuman primates. Studies show that some species of corvid (crows and ravens), such as New Caledonian crows (*Corvus moneduloides*), are deft toolmakers, mapmakers and timekeepers, particularly when they are hiding and retrieving food. These birds make a mental note of a food's "expiration date" when hiding it; they also check for onlookers while concealing their edibles—and, if any are present, stage an elaborate show to cover up what they are doing. Some corvid species are thought to exhibit considerable cognitive flexibility—the ability to recognize and adapt to changing circumstances—as well as planning, imagination and cooperative problem solving, aptitudes that had previously been ascribed only to primates.

This New Caledonian crow uses a twig as a tool to get at a concealed treat.

These findings challenge the conventional wisdom that the neocortex, a six-layered structure that forms the outer section of the mammalian brain, is a prerequisite for high-level faculties such as creativity and consciousness. Scientists had thought that animals such as birds, fish, amphibians and reptiles that lack this six-tiered neural edifice were largely incapable of tricky mental computations.

But the outer part of the avian endbrain, called the pallium, is now thought to perform functions, such as learning, similar to those of the mammalian neocortex even though it lacks distinct layers. The relative size of the pallium in corvids is much greater than it is in all other birds except parrots, hinting that this structure may mediate the faculties of New Caledonian crows. *—U.D. and G.R.*

Neither brain mass nor the ratio of brain to body mass can account for interspecies differences in intelligence.

birds and mammals and also in cetaceans and primates.

Heavy Thoughts?

What about the brain might underlie these parallel paths to astuteness? One candidate is absolute brain size [*see box on preceding page*]. Although many studies have linked brain mass with variations in human intelligence [see "High-Aptitude Minds," by Christian Hoppe and Jelena Stojanovic, on page 60], size does not always correlate with smarts in different species. For example, clever small animals such as parrots, ravens, rats and relatively diminutive apes have brains of modest proportions, whereas some large animals such as horses and cows with large brains are comparatively dim-witted. Brain bulk cannot account for human intelligence either: At eight to nine kilograms, sperm and killer whale brains far outweigh the 1.4 kilograms of neural tissue inside our heads. As heavy as five kilograms, elephant brains are also much chunkier than ours.

Relative brain size—the ratio of brain to body mass—does not provide a satisfying explanation for interspecies differences in smarts either. Humans do compare favorably with many medium and large species: our brain makes up approximately 2 percent of our body weight, whereas the blue whale's brain, for instance, is less than one 100th of a percent of its weight. But some tiny, not terribly bright animals such as shrews and squirrels win out in this measure. In general, small animals boast relatively large brains, and large animals harbor relatively small ones. Although absolute brain mass increases with body weight, brain

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DPA

mass as a proportion of body mass tends to decrease with rising body weight [*see box at right*].

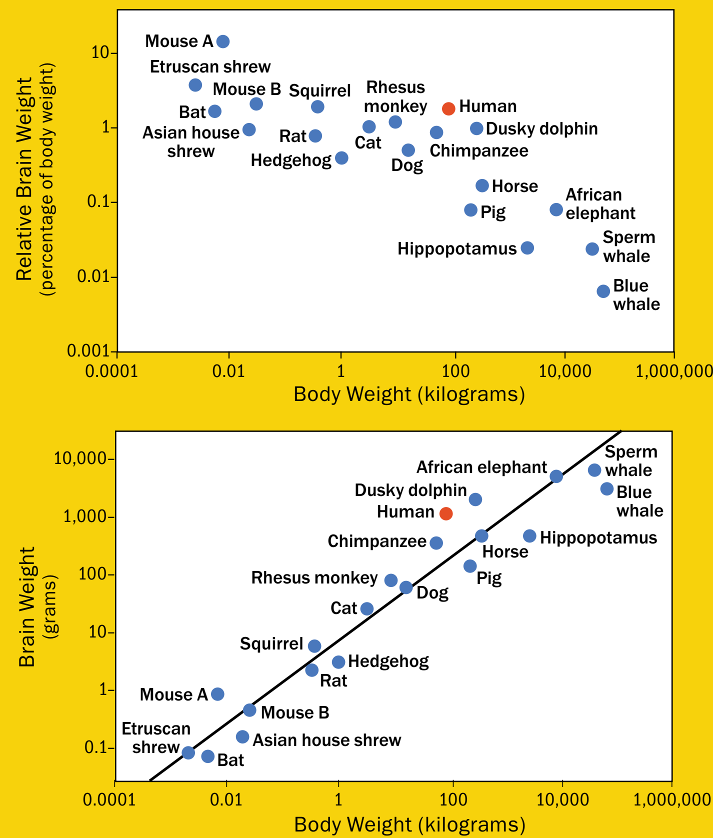
Another cerebral yardstick that scientists have tried to tie to intelligence is the degree of encephalization, measured by the encephalization quotient (EQ). The EQ expresses the extent to which a species' relative brain weight deviates from the average in its animal class, say, mammal, bird or amphibian [*see top box on next page*]. Here the human brain tops the list: it is seven to eight times larger than would be expected for a mammal of its weight. But EQ does not parallel intellect perfectly either: gibbons and some capuchin monkeys have higher EQs than the more intelligent chimpanzees do, and even a few prosimians—the earliest evolved primates alive today—have higher EQs than gorillas do.

Or perhaps the size of the brain's outermost layer, the cerebral cortex—the seat of many of our cognitive capacities—is the key. But it turns out that the dimensions of the cerebral cortex depend on those of the entire brain and that the size of the cortex constitutes no better arbiter of a superior mind. The same is true for the prefrontal cortex, the hub of reason and action planning. Although some brain researchers have claimed in the past that the human prefrontal cortex is exceptionally large, recent studies have shown that it is not. The size of this structure in humans is comparable to its size in other primates and may even be relatively small as compared with its counterpart in elephants and cetaceans.

Scientists regard prosimians such as Verreaux's sifaka (*above*) as less clever than other primates.

Top Heavy?

A weighty brain does not always mean quick wits: cleverness is lacking in some big-brained large animals as well as in some small animals with relatively massive cerebrums. Brain mass as a percentage of body weight decreases as body size goes up (*top*), but the absolute brain mass of animal species increases with their body weight (*bottom*).



NOTE: Scientists sampled two mouse species.

The lack of a large-scale measure of the human brain that could explain our performance may reflect the idea that human intellect may not be totally inimitable. Apes, after all, understand cause and effect, make and use tools, produce and comprehend language, and lie to and imitate others. These primates may even possess a theory of mind—the ability to understand another animal's mental state and use it to guide their own behavior. Whales, dolphins and even some birds boast some of these mental talents as well. Thus, adult humans may simply be *more* intuitive and facile with tools and language than other species are, as opposed to possessing unique cognitive skills.

Networking

Fittingly, researchers have found the best correlates for intelligence by looking at a much

GEHIRN & GEIST/CHRISTINA HOF; SOURCE: "BRAIN SIZE IN VERTEBRATES," BY P.A.M. VAN DONGEN, IN *THE CENTRAL NERVOUS SYSTEM OF VERTEBRATES*, EDITED BY R. NIEUWENHUYS, H. J. TEN DONKELAAR AND C. NICHOLSON, SPRINGER-VERLAG, 1998 (*graphs*); PETE OXFORD *Minden Pictures* (*sifaka*)

What's Your EQ?

The EQ compares a species' brain size with the expected brain size of a standard species (in this case, the cat) of its animal class (in this case, mammals).

Encephalization quotients (EQs) of selected mammals:

Human	7.4 to 7.8	African elephant	1.3
Dolphin	5.3	Walrus	1.2
Capuchin monkey	2.4 to 4.8	Camel	1.2
Gibbon	1.9 to 2.7	Dog	1.2
Chimpanzee	2.2 to 2.5	Squirrel	1.1
Old World monkeys	1.7 to 2.7	Cat	1.0
		Horse	0.9
Whale	1.8	Sheep	0.8
Marmoset	1.7	Mouse	0.5
Gorilla	1.5 to 1.8	Rat	0.4
Fox	1.6	Rabbit	0.4

smaller scale. Brains consist of nerve cells, or neurons, and supporting cells called glia. The more neurons, the more extensive and more productive the neuronal networks can be—and those networks determine varied brain functions, including perception, memory, planning and thinking. Large brains do not automatically have more neurons; in fact, neuronal density generally decreases with increasing brain size because of the additional glial cells and blood vessels needed to support a big brain.

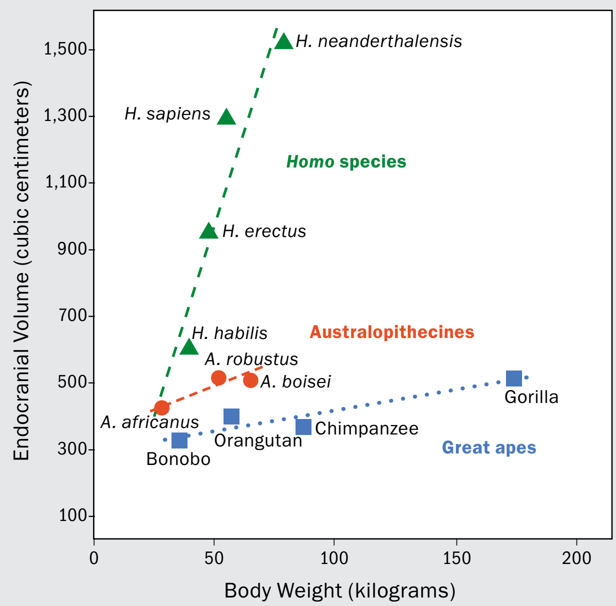
Humans have 11.5 billion cortical neurons—more than any other mammal, because of the human brain's high neuronal density [*see box on opposite page*]. Humans have only about half a billion more cortical neurons than whales and elephants do, however—not enough to account for the significant cognitive differences between humans and these species. In addition, however, a brain's information-processing capacity depends on how fast its nerves conduct electrical impulses. The most rapidly conducting nerves are swathed in sheaths of insulation called myelin. The thicker a nerve's myelin sheath, the faster the neural impulses travel along that nerve. The myelinated nerves in the brains of whales and elephants are demonstrably thinner than they are in primates, suggesting that information travels faster in the human brain than it does in the brains of nonprimates.

What is more, neuronal messages must travel

The human brain is densely packed with 11.5 billion cortical neurons—more than any other mammal.

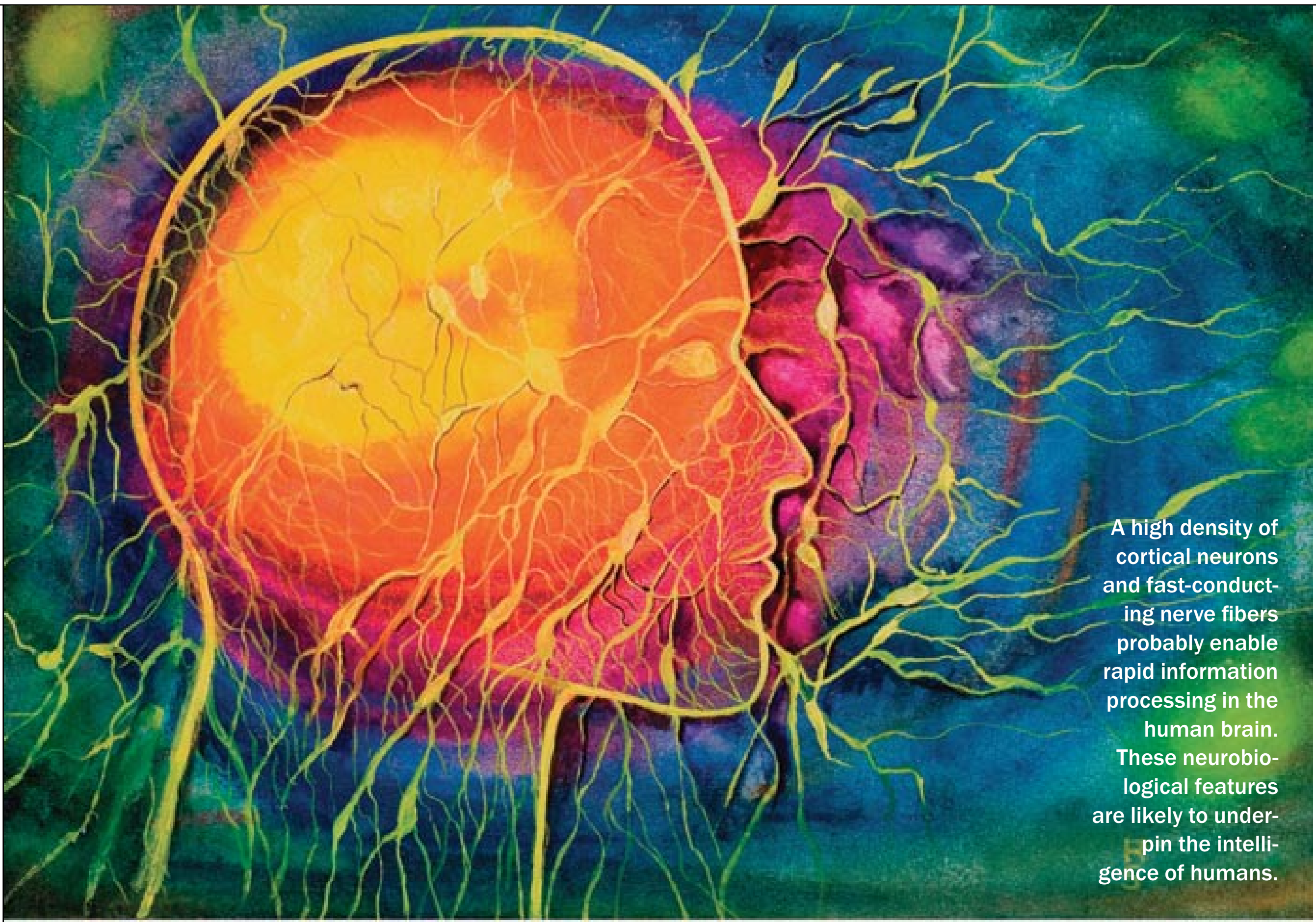
Steep Climb in Brain Size

Over evolutionary time, hominid brains grew in volume relative to body weight, a process known as positive brain allometry, and brain volume in the genus *Homo* increased more steeply than it did in the great apes and in the extinct australopithecines, which lived three million to four million years ago (*graph*). Hominid brains began to increase in size rapidly only about two million years ago: *Homo habilis,* which started to appear at about this time and used stone tools, had a brain volume of approximately 600 cubic centimeters as compared with the 450-cubic-centimeter australopithecine brain. By the time *H. erectus* arrived 1.8 million years ago, its brain volume was about 1,000 cubic centimeters. The brain of modern *H. sapiens,* which began to settle the earth about 100,000 years ago, is now about 1,350 cubic centimeters. (Paradoxically, Neandertals had huge brains, measuring roughly 1,500 cubic centimeters. The Neandertals buried their dead and produced very fine tools; just how intelligent they were is unknown.)



Traits such as upright gait and the use of tools developed long before the human brain became significantly larger than the primate average. Some researchers believe that the boost in brain growth rate was associated with a prolongation of childhood, during which the human brain continues to develop. —*U.D. and G.R.*

SOURCE: *EVOLUTION OF THE BRAIN AND INTELLIGENCE*, BY H. J. JERISON, ACADEMIC PRESS, 1973 (*EQ data*); SOURCES: "SIZE AND SCALING IN HUMAN EVOLUTION," BY D. PILBEAM AND S. J. GOULD, IN *SCIENCE*, VOL. 186, DECEMBER 6, 1974, AND JERISON (IBID.) (*endocranial volume data*)



A high density of cortical neurons and fast-conducting nerve fibers probably enable rapid information processing in the human brain. These neurobiological features are likely to underpin the intelligence of humans.

REINHARD SCHAFER *Getty Images* (*neurons*); SOURCE: HAUG (IBID.) (*neuron numbers*)

longer distances in the relatively large brains of elephants and whales than they do in the more compact human brain. The resulting boost in information-processing speed may at least partly explain the disparity in aptitude between humans and other big-brained creatures.

Among humans' cerebral advantages, language may be the most obvious. Various animals can convey complex messages to other members of their species; they can communicate about objects that are not in sight and relay information about individuals and events. Chimpanzees, gorillas, dolphins and parrots can even understand and use human speech, gestures or symbols in constructions of up to about three words. But even after years of training, none of these creatures develops verbal skills more advanced than those of a three-year-old child.

In humans, grammar and vocabulary all but explode at age three. This timing corresponds with the development of Broca's speech area in the left frontal lobe, which may be unique to humans. That is, scientists are unsure whether a direct precursor to this speech region exists in the nonhuman primate brain. The absence of an intricately wired language region in the brains of other species may explain why, of all animals, humans alone have a language that contains complex grammar. Researchers date the development of human grammar and syntax to between 80,000 and 100,000 years ago, which makes it a relatively recent evolutionary advance. It was also one that probably greatly enhanced human intellect. M

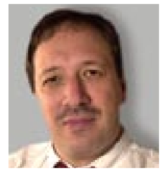
Brain Cell Census

Number of cortical neurons (millions)

Human	11,500	Rhesus monkey	480
African elephant	11,000	Squirrel monkey	480
Chimpanzee	6,200	Opossum	27
Bottlenose dolphin	5,800	Hedgehog	24
Gorilla	4,300	Rat	15

(Further Reading)

- **The Mentality of Crows: Convergent Evolution of Intelligence in Corvids and Apes.** N. J. Emery and N. S. Clayton in *Science,* Vol. 306, pages 1903–1907; December 10, 2004.
- **Evolution of the Brain and Intelligence.** G. Roth and U. Dicke in *Trends in Cognitive Sciences,* Vol. 9, No. 5, pages 250–257; May 2005.
- **Image Scoring and Cooperation in a Cleaner Fish Mutualism.** R. Bshary and A. S. Grutter in *Nature,* Vol. 441, pages 975–978; June 22, 2006.



D.I.Y. Addiction Cures?

Former drug and alcohol users can show impressive results without professional treatment, through the phenomenon of self-change

BY HAL ARKOWITZ AND SCOTT O. LILIENFELD

"To cease smoking is the easiest thing I ever did. I ought to know because I've done it a thousand times." —Mark Twain

SAMUEL CLEMENS (Twain was his nom de plume) humorously mocked his inability to end his nicotine-fueled habit. But he might have gone for Quitting Round 1,001 had he had the benefit of recent research.

In 1982 Stanley Schachter, an eminent social psychologist then at Columbia University, unleashed a storm of controversy in the addictions field by publishing an article show-ing that most former smokers and overweight people he interviewed had changed successfully without treatment. He also cited a study that reported even higher rates of recovery among heroin users without treatment.

A particularly controversial finding was that the success rates of his so-called self-changers were actually *greater* than those of patients who underwent professional treatment. Schachter discussed two possible explanations. First, treatment seekers may be more severely addicted than self-changers. Second, studies typically examine only one change endeavor, whereas his interviews covered a lifetime of efforts. Perhaps it takes many tries before a person gets it right, he suggested.

Schachter's findings were met with intense skepticism, even outright disbelief, particularly by those who believed in a disease model of addiction.

In this view, addictions are diseases caused by physiological and psychological factors that are triggered by using the substance (drugs or alcohol); once the disease is triggered, the addict cannot control his or her substance use, and complete abstinence is the only way to manage the disease. Proponents of this model did not believe that so many people could change their addictions at all, let alone without treatment. Other criticisms came from researchers who questioned the scientific value of Schachter's work because it was based on a small and selective sample and relied on self-reports of past behavior, which often are not accurate pictures of what really happened. Nevertheless, his findings served as a catalyst, encouraging many researchers to study self-change in addictive behaviors. Let us examine what the research tells us about how widespread successful self-change is for problem drinking and drug addiction.

Rates of Success

Psychologist Reginald Smart of the Center for Addiction and Mental Health in Toronto recently reviewed the findings on the prevalence of self-change efforts among problem drinkers. We draw the following conclusions from his review and from our reading of the literature:

- Most of those who change their problem drinking do so without treatment of any kind, including self-help groups.
- A significant percentage of self-changers maintain their recovery with follow-up periods of more than eight years, some studies show.
- Many problem drinkers can maintain a pattern of nonproblematic

COURTESY OF HAL ARKOWITZ (*top*); SCOTT O. LILIENFELD (*bottom*); NEWMANN *zefa/Corbis* (*woman holding up hand*); JUPITERIMAGES (*insets*) moderate use of alcohol without becoming readdicted.

- Those who do seek treatment have more severe alcohol and related problems than those who do not.

Although fewer studies of self-change in drug addiction exist, the results generally mirror those for problem drinking. In summary: self-change in drug addiction is a much more common choice for solving the problem than treatment is; a substantial percentage of self-changers are successful; a significant percentage of those who were formerly addicted continue to use drugs occasionally without returning to addiction-level use, and they maintain these changes fairly well over time; and those who seek treatment usually have more severe problems than those who do not.

The experiences of Vietnam veterans are especially instructive. Sociologist Lee N. Robins, then at the Washington University School of Medicine in St. Louis, and her associates published a widely cited series of studies beginning in 1974 on drug use and recovery in these veterans. While overseas, about 20 percent of the soldiers became addicted to narcotics. After discharge to the U.S., however, only 12 percent of those who had been addicted in Vietnam were found to be in that state at any time during the three-year follow-up. Fewer than 5 percent had overcome their addiction through therapy. Additional findings from Robins's studies suggested that abstinence is not necessary for recovery. Although nearly half the men who were addicted in Vietnam tried narcotics again after their return, only 6 percent became readdicted.

The results of Robins's studies suggest the power of self-change in drug addiction, but they also have been the target of many criticisms. For example, most men who became addicted in Vietnam had not had that problem before their tour of duty, suggesting that they may be unrepresentative of the general population of drug addicts. Moreover, their drug use may have been triggered by the stress of serving in Vietnam, making it easier for them to stop when they returned home. This last criticism is weakened, however, by the finding that most men who continued using some narcotics after discharge did not become addicted and by the fact that the return home was also very difficult because of the popular sentiment against that war in the U.S.

(We may learn a great deal from people who **successfully change** addictive behaviors on their own.)

Next Steps

We need more and better research on the potential for self-change to conquer problem drinking and other addictions. Studies suffer from differences in the definitions of important terms such as "addiction," "treatment" and "recovery." The use of reports of past behavior and relatively short follow-up periods are problematic as well. We also do not know of any studies on self-change with prescription drug addiction. Finally, we need to know if recovery from drug addiction leads to substitution with another addiction. At least one study revealed that many former drug addicts became problem drinkers. Because of these caveats and others, the percentages we have reported should be taken only as rough estimates.

Although we have reviewed some encouraging initial results from the literature, it is our impression that many addictions professionals do not view self-change as very effective. Their conclusion may be largely correct for those problem drinkers and drug addicts to whom they are typically exposed—treatment seekers.

Generalizations from those who seek treatment to the population of problem drinkers and drug addicts as a whole may be incorrect for two reasons, however. First, those who seek treatment have more severe problems than those who do not; second, they may overrepresent those who have failed repeatedly in their attempts at self-change.

We may learn a great deal from people who successfully change addictive behaviors on their own. Whatever they are doing, they are doing something right. In addition to the work with problem drinkers and drug addicts, we are beginning to make headway in the study of self-change in other problem areas, such as problem drinking, smoking, obesity and problem gambling. Greater knowledge about self-change and how it comes about might be used to help people who are not in treatment find ways of shedding their addictions as well as to enhance the effectiveness of our treatment programs. **M**

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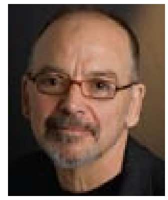
Send suggestions for column topics to editors@SciAmMind.com

(Further Reading)

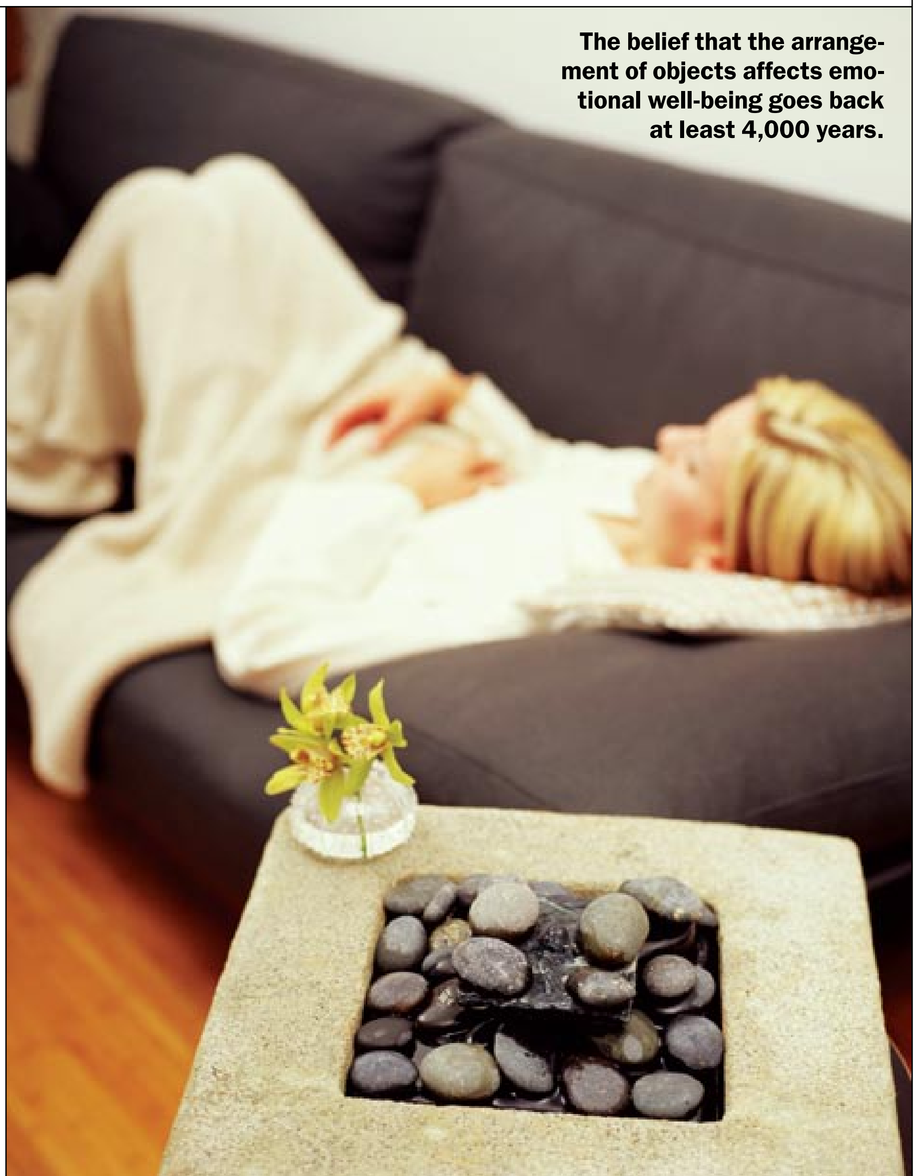
- **Vietnam Veterans' Rapid Recovery from Heroin Addiction: A Fluke or Normal Expectation?** L. N. Robins in *Addiction,* Vol. 88, No. 8, pages 1041–1054; August 1993.
- **Promoting Self-Change from Addictive Behaviors: Practical Implications for Policy, Prevention, and Treatment.** H. Klingemann and L. C. Sobell. Springer, 2007.

Arranging for Serenity



How physical space, thought and emotion intersect

BY WRAY HERBERT



The belief that the arrangement of objects affects emotional well-being goes back at least 4,000 years.

I AM A NEW AGE SKEPTIC. I used to be a New Age cynic, so this change shows how far I have come in opening my mind to things I do not understand. I no longer dismiss channeling and crystals and acupuncture as so much hocus-pocus, nor do I embrace these practices. I simply await proof.

I have to admit, though, that there is one New Age practice that has always had some intuitive appeal to me, and that's feng shui. Feng shui is the ancient Chinese art of placement, which is based on the belief that space and distance and the arrangement of objects can affect our emotions and our sense of well-being. This idea makes sense to me on a gut level: I know that I feel a greater sense of psychological equilibrium in some spaces than I do in others. I just do not know why.

Psychologists have some ideas about this connection among physical space and thought and emotion—or what they call "psychological distance." We have all had the sensation of being "too close" to a situation, needing to "get away" and "putting some distance" between ourselves and others. Our sense of emotional connectedness (or lack of it) is tightly entangled with our perception of geography and patterns in space.

Feel Crowded?

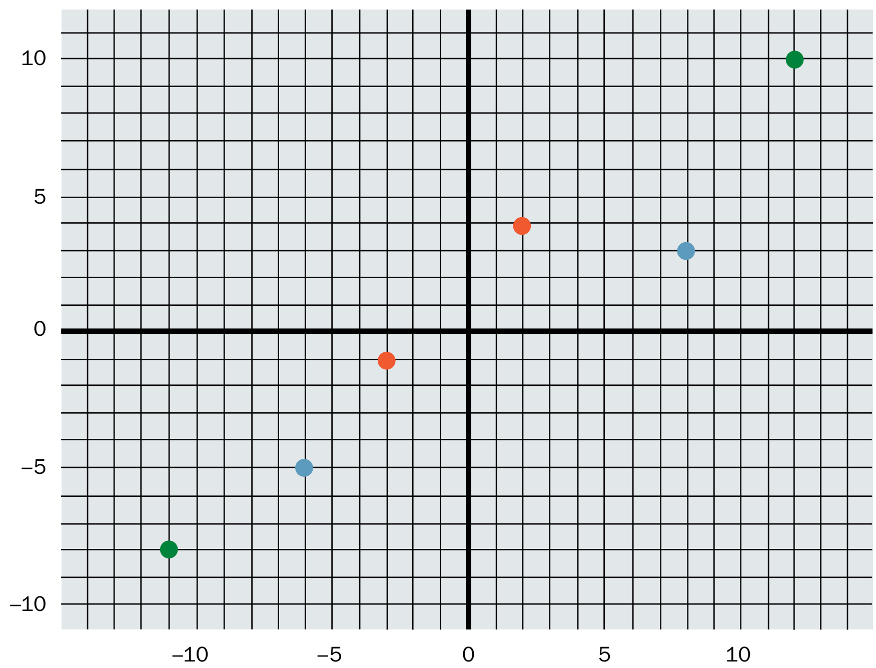
Two Yale University psychologists decided to explore the power of these perceptions in the laboratory, to see if indeed an ordered, open space affects people's emotions differently than a tighter, more closed-in environment does. Put another way, do we automatically embody and "feel" things such as crowding or spaciousness, clutter or order?

Lawrence E. Williams and John A. Bargh ran a series of experiments to explore this question. All the studies began with what is called priming—the use of a cue to create an unconscious attitude or sensation. The researchers used a simple but effective technique: they had respondents graph two points, just as a person would on an ordinary piece of graph paper. In some graphs the points were very close together (for example: coordinates 2, 4 and –3, –1), whereas in others they were far apart (12, 10 and –11, –8). This exercise is known to bolster people's unconscious feeling of either congestion or wide-open spaces.

Then the researchers tested the subjects in various ways. For example, in one study they had the participants read an embarrassing excerpt from a book, then asked them questions such

MATT MENDELSOHN (*Herbert*); JUPITERIMAGES (*woman on sofa*)

Our sense of **emotional connectedness** is tightly entangled with our perception of geography and patterns in space.



SPATIAL PRIMING: When students are asked to graph a pair of points (*red, green* and *blue*), the distance between the points influences their emotional response to subsequent situations, affecting whether an experience is, for example, enjoyable or embarrassing. People who are primed for closeness, as opposed to spaciousness, even report weaker bonds to their parents.

as whether the passage was enjoyable or entertaining and whether they would like to read more of the same. Williams and Bargh wanted to see if a sense of psychological distance or freedom might mute emotional discomfort, and that result is exactly what they found. The volunteers who had been primed for spaciousness were less discomfited by the embarrassing experience; they found it much more enjoyable than did those who had a more pinched perception of the world.

The psychologists ran another version of the same experiment, in which the book excerpt was extremely violent rather than embarrassing. They got the same basic results. Subjects who had been primed for closeness found the violent events much more aversive—just as we find an airplane crash in our own neighborhood more upsetting than a crash 3,000 miles away. Williams and Bargh believe this tendency has to do with the brain's deep-wired connection between distance and safety, a habit of mind that probably evolved to help our hominid forebears survive in precarious conditions.

Peril and Distance

The psychologists wanted to explore more directly this link between psychological distance and real peril. As described in the March *Psychological Science,* they primed the participants' minds in the usual way, then had them estimate the number of calories in both healthy food and junk food. They reasoned that the calories in french fries and chocolate are perceived as a health threat—emotionally dangerous—whereas the calories in brown rice and yogurt are not, and that people primed for closeness would be more sensitive to the threat. And that is what they found: those people who had been made to feel crowded and closed in thought there were more calories in junk food than did those who felt open and free. The two groups' perceptions of healthy food were identical.

That is pretty convincing. But Williams and Bargh decided to run one more test, one that dealt head-on with the issue of personal security. The researchers asked all the subjects about the strength of their emotional bonds to their parents, siblings and hometown, and they found that those who had been primed for greater psychological distance reported weaker ties even to these important emotional anchors. Or, put another way, those subjects had more emotional detachment from the situation.

What is remarkable is that this all takes place unconsciously, apart from awareness: the spatial distance between two arbitrary objects (in this case, two mere dots on a graph) is apparently powerful enough to activate an abstract symbol of distance and safety in the brain, which in turn is powerful enough to shape our responses to the world. It is almost enough to make me move that vase a bit farther from the sofa and just a bit closer to that lamp over there. **M**

For more insights into the quirks of human nature, visit the "We're Only Human ..." blog and podcasts at www.psychologicalscience.org/onlyhuman

WRAY HERBERT is director of public affairs for the Association for Psychological Science.

(Further Reading)

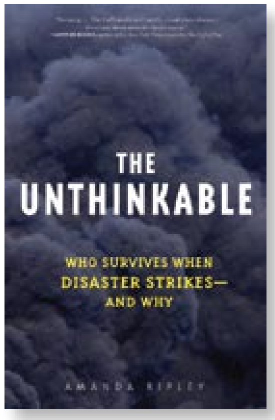
- **Keeping One's Distance: The Influence of Spatial Distance Clues on Affect and Evaluation.** Lawrence E. Williams and John A. Bargh in *Psychological Science,* Vol. 19, No. 3, pages 302–308; March 2008.

SOURCE: WILLIAMS AND BARGH, 2008

> WOULD YOU PANIC?

The Unthinkable: Who Survives When Disaster Strikes—and Why

by Amanda Ripley. Crown Publishers/Random House, 2008 ($24.95)



Your plane just crash-landed. You can't see anything through the suffocating smoke around you, yet you know you have to get out of the plane. Do you jump up and feel your way to the nearest emergency exit or stay put, paralyzed with fear? Do you help others around you or fend only for yourself? What factors determine who you are in the face of disaster?

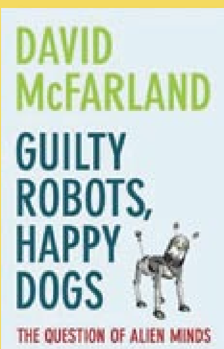
These are questions veteran *Time* journalist Amanda Ripley addresses in her harrowing book *The Unthinkable.* Through the riveting accounts of survivors of natural disasters, plane crashes, fires and terrorist attacks, Ripley illustrates that every person responds to crisis differently. These differences, she learns through interviews with experts ranging from neuroscientists to risk analysts, are determined by both biology and experience.

For example, soldiers who produce high levels of a stress-related brain chemical called neuropeptide Y are much more likely to pass the rigorous training tests required for admission into the selective U.S. Army Reserve. But survival is about more than chemicals: a person can, to a certain degree, affect his or her chances in trying situations. People who were in the World Trade Center on 9/11 were much more likely to survive if they had participated in fire drills. (Many people, Ripley explains, did not even know where the nearest staircases were.) Similarly, experienced police and firefighters—and people who have survived previous disasters—perform better in crises than do those who have never encountered tragedy.

Because experience is so critical, Ripley raises an important question: Why isn't disaster preparedness more integral to our culture? Many American cities are built on fault lines and in hurricane hotspots. "Largely because of where we live, disasters have become more frequent," she writes. "But as we build ever more impressive buildings and airplanes, we do less and less to build better survivors." Luckily, she says, it is possible to self-educate: people who take simple steps such as checking the locations of stairways and exits are in a much better position to take action if they ever find themselves in a crisis.

Ripley has accomplished a rare feat in *The Unthinkable.* In a page-turner as exciting as any mystery novel, she has delivered insight into a scientific mystery, voiced an important and convincing political plea, and collected a handful of tools that readers can use to empower themselves in the unfortunate face of tragedy. —*Melinda Wenner*

Mind Reviews



> FIDO THE PHILOSOPHER

Guilty Robots, Happy Dogs: The Question of Alien Minds

by David McFarland. Oxford University Press, 2008 ($34.95)

You may not see a connection between your poodle and a robot of the future, but David McFarland thinks that they have a lot in common: both are "alien minds." Accordingly, McFarland says, if we want to answer the long-standing question of whether robots can have minds, we need to look no further than our animal aliens.

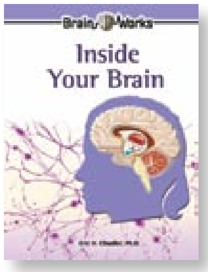
Do animals have minds? And if they do, how would we know? In *Guilty Robots, Happy Dogs,* McFarland, a British animal behaviorist, takes a look at the various scientific and philosophical approaches people have employed to address these questions. Although his accounts are sometimes tedious, McFarland has succeeded in writing about philosophy in a way that the lay reader can follow. He covers topics ranging from the interpretation of behavior to what he calls the "feeling of being" and gives examples of animal behavior that appears to be rooted in conscious thought. For example, when a fox approaches an incubating sandpiper, the bird limps away from its nest, pretending to be injured. Once it has lured the predator far enough away, it flies off. McFarland shows, however, that both the bird's and the predator's behavior may be explained with or without the existence of mental states in these animals.

Rather than giving definite answers, *Guilty Robots, Happy Dogs* raises a number of thought-provoking questions. For example, does a dog experience pain if someone gently squeezes its injured paw? Most people would probably answer "yes," McFarland says. But what about the rooster that lived on for another 18 months after a Colorado farmer decapitated it? Fed with an eyedropper directly into its throat, the bird gained five and a half pounds, walked around and even attempted to crow. Would that animal experience pain?

After examining the question of alien minds from all angles, McFarland surmises that most of the attributes suggesting mental processes in animals can be achieved without thought: "Probably all the phenomena that have been cited as evidence that animals have some kind of mentality have also been demonstrated in robots." He ultimately leaves the reader with only one conclusion: we will never really know if robots can feel guilty or if dogs can be happy. —*Nicole Branan*

>> Back to School

Inquisitive kids love learning about the brain. For those still a little too young to read *Scientific American Mind,* here are some excellent book and DVD choices:



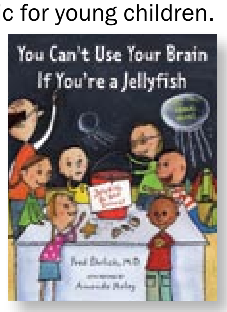
Why does the family dog have such a better sense of smell than Mom or Dad does? In ***Inside Your Brain*** (Chelsea House Publishers, 2007), neuroscientist Eric H. Chudler answers this question and many more concerning how different parts of the brain work, why we experience emotions, and what happens in our head when we sense, sleep and remember. Games, experiments and illustrations help to elucidate the complex ideas for kids 11 years old and up.

With autism increasingly in the news, some children might be curious about what life is like for kids who have the developmental disorder. ***Autism: The Musical*** (HBO Documentary Films, 2007) follows five autistic children as they exceed expectations by writing and performing their own musical with the help of their families. Buy the DVD online at www.cduniverse.com

Tourette's syndrome may affect up to 1 percent of all kids in the U.S. In the Emmy Award–winning documentary ***I Have Tourette's, but Tourette's Doesn't Have Me*** (HBO, 2005), more than a dozen children aged six to 13 describe the challenges they face living with the tic disorder. Buy the DVD online at www.tsa-usa.org

Why does a raspberry taste different than a blueberry? How can we tell whether we are seeing a small tree up close or a big tree far away? In a series of five books for

six- to eight-year-olds called ***Hearing***, ***Seeing***, ***Smelling***, ***Tasting*** and ***Touching*** (Capstone Press, 2006), author Rebecca Olien uses colorful photographs and drawings to imaginatively explain how our five senses work.



Neuroanatomy is not typically a topic for young children. Physician Fred Ehrlich, however, has created a bright and engaging book for kids ages seven to 11 that describes different types of animal brains ranging from a worm's to a human's. See how these organs work and what they can do in ***You Can't Use Your Brain If You're a Jellyfish*** (Blue Apple Books, 2005).

—Victoria Stern

CINDY GOLD (Autism: The Musical)

> PARALYZED BY CHOICE

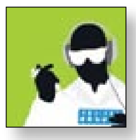
Quid Pro Quo

HDNet Films, 2008

In a dark New York City basement, reporter Isaac Knott finds a group of people sitting in wheelchairs, talking in hushed voices. A woman moves her legs. To his surprise, Isaac realizes he has interrupted a support group for able-bodied people who want to be like he is: paralyzed and confined to a wheelchair.

These are characters in the feature film *Quid Pro Quo,* and they have variants of body integrity identity disorder (BIID), a rare psychiatric illness that causes people to feel alienated from their own body parts [see "Amputee Envy," by Sabine Mueller; Scientific American Mind, December 2007/January 2008]. Members of the fictional support group go by the real-life slang for their particular desire: a "pretender" wears a nonworking breathing tube, and "wannabes" strive to become disabled by ingesting a paralyzing chemical or by bribing doctors to sever their limbs.

Isaac quickly falls for Fiona, a beautiful woman attached to her unnecessary antique Milwaukee back brace. Filmmaker Carlos Brooks takes creative liberties to explain Fiona's behavior, melding various explanations for BIID. Unfortunately, he misses the mark by focusing on the more bizarre and titillating elements of the disease, ignoring the latest neurological findings that brain damage may be the root of some cases. The movie and its treatment of BIID veer off course when both Isaac's and Fiona's symptoms fluctuate wildly and unbelievably. Though surreal, the film deserves credit for daring to raise the question, Why would someone who isn't paralyzed want to be? *—Corey Binns*



> NATURE RADIO

NeuroPod

Listen at www.nature.com/neurosci/neuropod

Neuroscience podcasts seem to be all over the Internet these days, but one stands out for the true science aficionado: NeuroPod. Researcher-turned-journalist Kerri Smith hosts this podcast from the journal *Nature,* in which she interviews leading scientists about their latest discoveries. Each episode's four stories are hot off *Nature*'s presses or straight out of a recent neuroscience meeting.

Every month NeuroPod explores a variety of topics that relate to common thoughts, behaviors and choices. Why do certain memories, such as a family vacation or the time our favorite baseball team came from behind for a victory, elicit emotional responses? Why is exercise so good for our mind? And why do fruit flies have a genetic switch that triggers homosexual behavior?

Smith skillfully tackles such questions in each episode's fast-paced, seven-minute interviews. As the researchers dissect their latest studies, they delve into the inner workings of the brain. Although the in-depth explanations occasionally become dull or convoluted, more often than not they provide satisfying "aha" moments: "So *that's* why teenagers make such rash decisions!" NeuroPod offers insights into your mind straight out of the world's top research labs. *—Victoria Stern*

askthe**Brains**

Can one neuron release more than one neurotransmitter?

—Marvin Shrewsbury, Wailuku, Hawaii

Rebecca Seal, a neuroscientist at the University of California, San Francisco, replies:

WHEN DISCUSSING neurotransmitters, most people think of the classical neurotransmitters, such as dopamine and serotonin—the primary chemical messengers used by neurons to communicate with one another and with other types of cells. In the early 20th century physiologist Sir Henry Dale hypothesized that an individual neuron releases the same classical neurotransmitter from all its axons, the spindly branches that jut out from the main cell body. Another prominent scientist of the time, Sir John Eccles, restated Dale's principle to also mean that a neuron releases only one neurotransmitter. From that point on, the concept of "one neuron, one transmitter" became widely accepted.

Neuroscientists now know, however, that it is common for neurons to release a classical transmitter with another type of messenger, such as a gas (nitric oxide, for instance) or a neuropeptide (a small protein that can act as a transmitter). With the aid of new techniques for manipulating and imaging neurons, researchers have found that a number of neurons communicate using more than one classical neurotransmitter. Indeed, some of our auditory neurons simultaneously release three different classical transmitters during a brief period in development.

So we see that "one neuron, one transmitter" is a bit too simplistic. But what about the original principle put forth by Dale that all axonal branches of a neuron release the same transmitter? There now appear to be at least a few exceptions to this principle. Motor neurons, which are important for voluntary muscle movements, have long been known to release acetylcholine onto both muscle cells in the body and neurons in the spinal cord. Recent studies show, however, that motor neurons also release a second transmitter, glutamate. Remarkably, they appear to release glutamate only onto neurons in the spinal cord and not onto muscle cells—in other words, certain branches of a single neuron release glutamate, and others do not.

A next step in neurotransmitter research will be to understand how the release of more than one messenger affects the function of the neural circuit and the organism as a whole. The fundamental question you ask has led to nearly a century of fascinating research, and it will continue to be an active and exciting area of investigation.

A number of neurons communicate using more than one classical neurotransmitter. Some of our auditory neurons release three different transmitters.

Why is it comforting to discuss problems with others?

—Celine Joiris, via e-mail

Dinah Miller, a psychiatrist in private practice in Baltimore and a part-time faculty member at Johns Hopkins University, explains:

WHEN PEOPLE seek comfort in talking, they may be looking to unburden themselves of a secret or seeking validation for their beliefs. Sometimes they want reassurance that nothing is terribly wrong with them. Psychotherapy, or talk therapy, has traditionally been part of the treatment for mental disorders; the process of talking is itself instrumental in alleviating such problems.

It is refreshing that your question asks why talking is comforting and not why talking is curative. It can be difficult to assess what features of psychotherapy are healing; it is easier to break down the components of why a patient may feel comforted. The question does not specifically address the talking of psychotherapy as opposed to the talking that occurs between friends or in a support group, but many helpful elements are shared by all these settings.

The primary factor that yields comfort is the relationship between the distressed person and the listener. It is vitally important that the speaker feels heard and that he or she has the opportunity to discuss a situation in an open and accepting environment. Often people seek out listeners who have been through the same experience and can offer true empathy. For the sake of completeness, I should say that talking does not comfort everyone.

In *Persuasion and Healing* (Johns Hopkins University Press, 1961), psychiatrist Jerome Frank made the case that the most important characteristics of a psychotherapist are empathy, warmth and genuineness. Certainly these features are subject to opinion and perception, such that not every patient feels helped by every therapist. Similarly, in everyday life, people may find that one of their friends is the right person to listen to some of their problems, whereas another is better at listening to different problems. M

Have a question? Send it to editors@SciAmMind.com

COURTESY OF REBECCA SEAL AND DINAH MILLER

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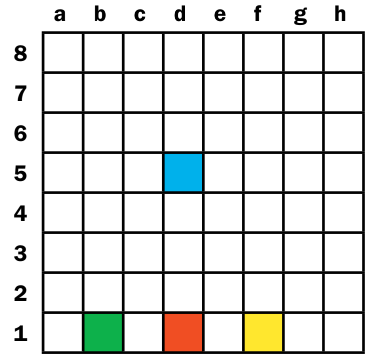
Head Games
Match wits with the Mensa puzzlers

1 A REAL BUGGER



The bee moves in a beeline, either three spaces horizontally, three spaces vertically or two spaces diagonally.

The grasshopper jumps straight over another bug. It lands the same distance away from the bug, but on the other side.

The ladybug flies from wherever it is to the exact middle between two bugs. (Accordingly, the other two bugs must be on the same line and have an odd number of spaces between them.)

Your challenge is to get all three bugs from their present location to the blue square in nine moves.

2 TWIDDLE-TWADDLE

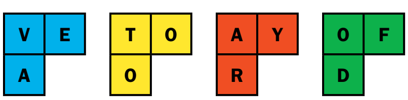
On the island of Twiddle-Twaddle live two groups of people. The Twiddles always tell the truth, unless a Twaddle is present; then the Twiddles will lie.

The Twaddles always tell the truth, unless more Twiddles are present than Twaddles; then the Twaddles will lie.

Three islanders, Alison, Betty and Cathy, are sitting together. Betty says, "Only two of us are Twiddles." To which group does each of these ladies belong?

5 JIGSAW

Fit together these three-letter puzzle pieces to make seven words, ranging in length from two to five letters. You may not rotate or flip the pieces.



3 A-E-I-O-U

Fill in each blank below. All the missing words have the same pattern of consonants, but each word contains a different vowel.

_____ week I saw a man. "I've made a _____," he said, "of all the loves I have _____." I spoke not, _____ he grow angry, but I had the thought: This is not love but _____.

4 CUT AWAY

Start with a six-letter word. At each step remove a letter, creating a word that matches the given clue.

_ _ _ _ _ _	**grow**
_ _ _ _ _	**fountain**
_ _ _ _	**dog**
_ _ _	**drunk**
_ _	**__ Peter**

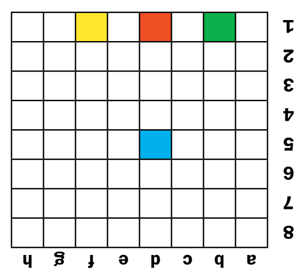
6 MISSING PIECES

Fill in the blanks according to the clues.

a)	_ T I R _ E _	Not a martini option for Bond
b)	_ _ T I R E	Whole
c)	T I _ _ _ R E _	Attempted a do-it-yourself repair
d)	T I R _ _ E	Verbal assault
e)	T _ I _ _ R E _	Customized
f)	_ _ T I _ R _ _ _ E	Popular engine additive
g)	T _ I R _ _ E _	Object of triskaidekaphobia
h)	T _ I R _ E _	Manipulated a baton
i)	T I _ R E _	Like many wedding cakes
j)	_ _ _ T I _ _ _ R _ E _	Places that manufacture some hard stuff

Answers

1. We found this path:



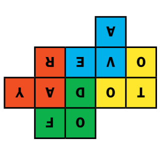
1) B to d3
2) G to f5
3) B to b5
4) L to d5 (home)
5) B to e5
6) G to d5 (home)
7) B to c3
8) B to f3
9) B to d5 (home)

2. If there were two Twiddles and one Twaddle, then no matter who she was, Betty would have to lie, and she could not make the statement she did. If there were three Twiddles, her statement would be a lie—but Betty could not lie in that situation. Similarly, if there were no Twiddles, Betty would have to tell the truth. Therefore, there must be two Twaddles and one Twiddle. But the Twaddles in this case will not lie, so Betty has to be the only Twiddle.

3. Last, list, lost, lest, lust

4. Sprout, spout, Spot, sot, St.

5.



6. a) STIRRED
b) ENTIRE
c) TINKERED
d) TIRADE
e) TAILORED
f) ANTIFREEZE
g) THIRTEEN
h) TWIRLED
i) TIERED
j) DISTILLERIES

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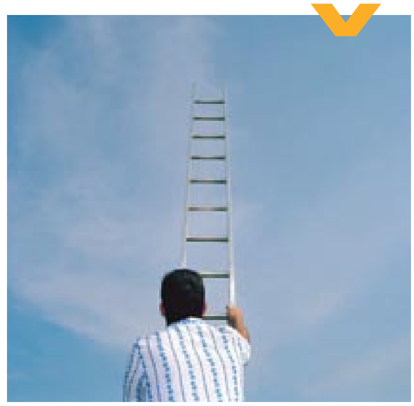

Seekers of the Unknown

Researchers are exploring what makes some people restless adventurers and others creatures of convention and habit.

Limits of fMRI

Brain scans have given us compelling pictures of "modules" for thinking. Do they also give us an oversimplified view of our thought processes?

Putting Thoughts into Action

Neural prosthetics relay the brain's instructions to electronic devices, giving one paralyzed patient the chance to speak—and yielding new insight into the mind.

PLUS:

Ask the Brains Does napping affect learning and memory? Why do we find it funny when someone falls down?

Illusions Play tricks on your brain—and gain insights about mental functions.

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DAVID TROOD *Getty Images (left)*; WINDSOR & WIEHAHN *Getty Images (right)*