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SCIENTIFIC AMERICAN MIND

BEHAVIOR • BRAIN SCIENCE • INSIGHTS

November/December 2014
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SPECIAL ISSUE

THE FUTURE YOU: What's Next in Brain Health

LIGHTING UP NEURONS to change behavior

ELECTRIC PHARMACY Next-generation treatments

BRAIN-TO-BRAIN COMMUNICATION A direct link

HUMAN CYBORGS reveal how we learn

USING BRAIN WAVES to fly a plane

DIGITAL SOS How to help a friend

SILENCING CYBERBULLIES We all play a role

PLUS: SMARTPHONE THERAPY 10 apps to try

COVER IMAGE BY VAULT 49 (*photoillustration*) AND AARON GOODMAN (*photography*); SEAN McCABE (*Upson*)

Happy Birthday to Us

A little more than a decade ago the editorial and business executives at *Scientific American* noticed a curious trend. Readers always snapped up issues that featured the brain. A German sister publication had picked up on this enthusiasm as well and had recently launched a magazine on the brain sciences, called *Gehirn & Geist*.

The team at *Scientific American* decided to release its own test issue on the mind and brain in early 2004. To everyone's astonishment, newsstands sold out of nearly every copy. The data suggested that people hungered to learn more about the way they think. By the end of the year *Scientific American Mind* had officially launched.

Ten years on, the magazine now has its own stable of seven international editions, as well as a tablet edition and a thriving Web presence. The issues still come out every two months, but new articles appear online daily. As we reflected recently on our own evolution, we decided to also look forward to what the next 10 years might bring. In this issue's special report,"The Future of the Brain," starting on page 28, we describe the trends that intrigued us most. The common theme in all of them is technology, which is opening up new frontiers in mental health and cognitive enhancement.

A key reason is that brains and computers communicate in dialects of the same language. They both transmit information using electricity. So it is only natural that emerging technologies are harnessing that shared lexicon to tease out the roots of disease, the building blocks of learning and the neural representations of thoughts. Scientists are also making use of the brain's electrical nature to tinker with it—to overcome illness and boost select abilities.

The power of technology is evident not only inside the brain but also outside it, in the ways we maintain relationships. For example, the impoverished social cues that often accompany interactions on social media are giving rise to new behaviors—some that bring us closer together and others that cause harm. Psychologists are just beginning to make sense of our partly digital psyches.

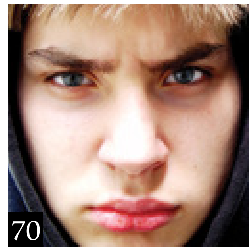
We believe that the themes highlighted in this special issue will resonate for years to come. What do you think? Drop us a note at the e-mail address below or reach out to us on Twitter (@sciammind) or through our Facebook page. Whatever your preferred technology, we'd love to stay connected.

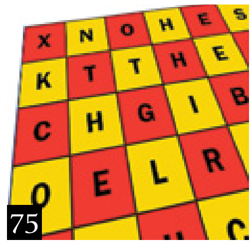
Sandra Upson
Managing Editor
editors@SciAmMind.com

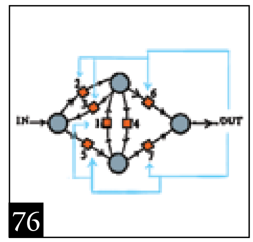
VOLUME 25, NUMBER 6, NOVEMBER/DECEMBER 2014

FEATURES

DEPARTMENTS







Scientific American Mind (ISSN 1555-2284), Volume 25, Number 6, November/December 2014, published bimonthly by Scientific American, a trading name of Nature America, Inc., 75 Varick Street, 9th Floor, New York, N.Y. 10013-1917. Periodicals postage paid at New York, N.Y., and additional mailing offices. Canada Post International Publications Mail (Canadian Distribution) Sales Agreement No. 40012504. Canadian BN No. 127387652RT; TVQ1218059275 TQ0001. Publication Mail Agreement #40012504. Canada Post: Return undeliverables to 2835 Kew Dr., Windsor, ON N8T 3B7. Subscription rates: one year (six issues), $19.95; elsewhere, $30 USD. Postmaster: Send address changes to Scientific Americ-an Mind, P.O. Box 3187, Harlan, Iowa 51537. To purchase additional quantities: U.S., $10.95 each; elsewhere, $13.95 each. Send payment to SA Mind, P.O. Box 4002812, Des Moines, Iowa 50340. **For subscription inquiries, call (888) 262-5144. To purchase back issues, call (800) 925-0788.** Printed in U.S.A.

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LETTERS JULY/AUGUST 2014 ISSUE

CURIOUS AND CREATIVE

I just finished reading "Creativity Is Collective," by S. Alexander Haslam, Immaculada Adarves-Yorno and Tom Postmes, and enjoyed it very much. I am a partner and creative director at a Toronto-based graphic design firm and always look forward to anything you publish on the subject of creativity.

After spending many years participating in and observing the creative process, I found myself searching for explanations as to what makes for a successful and gratifying collaboration. That search led me to a close examination of curiosity and its importance in creativity. Over the past few years I've lectured to designers and students throughout North America about curiosity and written several articles on the subject.

Last year I noticed an unusual dynamic while our studio was producing "Bees," an issue of *Wayward Arts* magazine. The younger designers on our team did not contribute nearly the quality of ideas and energy as our senior designers. In trying to understand why, I isolated several areas where I believe these young designers had difficulties—areas of the creative process that they will need to strengthen:

1. Have a tolerance for ambiguity.
2. Feel confident in sharing ideas, even bad ideas.
3. Heighten your sense of curiosity and discovery.
4. Know that mistakes are part of the process and that they will teach you valuable lessons.

Perhaps our experience of creating "Bees" and the intriguing issue that surfaced can provide insights for people who want to become more creative.

Bob Hambly
Toronto

UNRELENTING AROUSAL

As one who suffered from restless genital syndrome (ReGS) for six years, I appreciate your publishing Cat Bohannon's comprehensive coverage of Sally's case in "When Arousal Is Agony."

The symptoms described were very similar to my own, lasting for hours without respite, often leading to bouts with depression. I appreciated Bohannon's reporting on what little research has been done on the causes of this syndrome and her listing many of the treatments that are available. She accurately states that it is still not certain whether the very expensive surgically placed transmitter permanently cures people.

I have taken a different course of treatments, including unsuccessfully trying many drugs, hormones and supplements that seemed to help others. In addition, my physician tried about a dozen different homeopathic remedies with me. That seemed to make the difference, and I'm happy to say I am about 90 percent better, or 90 percent ReGS-free.

It has been a long, arduous journey, like a roller coaster ride. Because I had ReGS for so long, I often thought I might never get better. I'm very thankful today for my doctor and his persistence. I have a lot of compassion for those who struggle with it and hope they can find relief like I did.

Cheryl Iantorno
via e-mail

It was a bit startling to read the following at the start of Bohannon's article: "A woman we'll call Sally lived in a small town deep in the heart of Texas hill

CLARIFICATION

Because of a misunderstanding by the editors, "Posers and Fakers," by Susana Martinez-Conde and Stephen L. Macknik [Illusions], printed only two of the three images necessary to see artist Heather Spears's "baby head" illusion. The full illusion is at the left. Spears noticed that when she sketched from a photograph faithfully (*center*), the result did not look as much like the real baby as when she drew intuitively (*right*).

country.... It's mostly middle class, mostly Christian, the sort of place where you don't have to lock your doors because you already know all your nosy neighbors."

The implication is clear: Areas where Christians live are safe. Areas with "others," not so much. The writer may have meant to write about homogeneity, not religion, and this kind of bias is often introduced unconsciously—but this is journalism. One has to be accurate. Being "Christian," throughout the movement's long history, has not always or universally been equated with "supernice, supercaring, always ethical, never violent."

It's a particular shame to see this kind of bias in a magazine that reports on scientific findings. I hope future articles allow for the possibility of violence by and among people who are Christian and of peaceful relations by and among people who are not Christian.

Rachel Adelson
via e-mail

DREAMS REMEMBERED

I found both the answers to the questions in Ask the Brains fascinating. But in the response to "What processes in the brain allow you to remember dreams?" I was rather surprised to see the claim that if a dream ends before you wake, you will not remember it. I do not think that this claim is true for everyone. I am a chronic insomniac, and when I do sleep I have the feeling of still being partly conscious. Thus, I tend to be aware that I am asleep in my bed, dreaming. When I wake up, I have found that sometimes I not only remember the dream I have just experienced but also the one before and, on occasion, the one before that! So although "normal" sleepers may be unable to recall dreams that end before they wake up, it is possible that light sleepers or those with other sleep problems can. Such people would make an interesting population to study and may reveal some novel findings not just about sleep but about consciousness as well.

Jo Saunders
University of Strathclyde, Glasgow

So much in our biology is not random, and so it goes with our dreams. When we do remember them, there is probably a reason. The way I see it, we are often working on problems in dreams that we couldn't solve in waking life. As a clinician, I assume that when a client recalls a dream, he or she probably wanted to bring its topic into our session for discussion. As we talk, the client usually figures out what the reverie was about (that is, what problem he or she is working on).

I generally ask clients how they felt when they awoke—were they startled, depressed, fearful, quizzical? These emotional states can also provide information about the meaning of a dream.

"lynnoc"
commenting at
Mind.ScientificAmerican.com

SAFE TRAVELS

"Channel your younger self," the third tip in "How to be a Better Traveler," by Sunny Sea Gold [Head Lines], sounds like horrible advice to me. For most of us, our younger selves were fairly stupid and never thought about consequences. A good example is when my wife traveled to Italy in college and was essentially held captive by a Naples taxi driver. If you've developed instincts for potential dangers over the years, it's pretty dumb to rationalize them away by channeling your younger, dumber self.

"methos1999"
commenting at
Mind.ScientificAmerican.com

Having traveled extensively as a teenager, I get a laugh out of the comment from "methos1999." I traveled the globe by hitching rides, taking trains and hiking on foot through some of the worst slums in the world. I visited countless people's homes and shared and enjoyed many a meal. Of course, I was traveling in the early 1970s, with a buddy, when flower power was the code of the young generation, but I still had my share of run-ins with seedy people and their evil doings. Somehow I survived encounters with drug addicts, pedophiles, drunk drivers, grifters, gypsies, felony criminals of every sort and even some of the meanest cops in America.

I not only survived but gained wisdom and insight that only those kinds of encounters could give me. I would do it all over again with even fewer inhibitions if I could. The worst that can happen is you can die, and that consequence is a real possibility no matter what you do in life.

"singing flea"
commenting at
Mind.ScientificAmerican.com

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Head Lines

EXPLORING HOW WE ARE WIRED

Your Brain, Enhanced

ILLUSTRATIONS BY RADIO

M NEWS FROM OUR WEB SITE | New evidence finds that dogs experience jealousy, an emotion long believed to be unique to humans.

Upgrading the Brain

Technology is shaping our thinking about mental abilities and their improvement

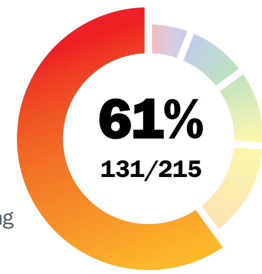
If you could enhance just one aspect of your brain, what would you choose? We recently asked online readers this question and received a bevy of creative responses. As we sifted through your 215 specific suggestions, we noticed a trend. Many of you used the language of technology—random-access memory, SD cards—to describe the brain's features and abilities. Clearly, the prevalence of smartphones and computers has shaped the way we think about mental abilities.

This technology focus may explain why the most popular upgrade was memory, with a whopping 25 percent of the total votes. Our data-packed devices remind us routinely of the value of enhanced access to information. Yet the growing prevalence of dementia, which affects 35.6 million people worldwide, might also make memory especially salient. Fortunately, scientists are developing ways to help combat its loss. One novel approach employs ultrasound to strengthen the power of drug treatments [see "The Sound of Healing," below].

Another highly rated desire was to learn better—often to

Cracking Cognition

Readers wanted to master:
52 (40%) Memory
25 (19%) Learning
21 (16%) Rationality
20 (15%) Focus
13 (10%) Creativity and problem solving



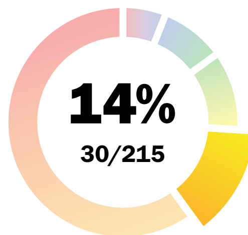
I'd love to upload books straight to my brain.
—*Rana Matared*

Flawless memory. You'd never need to study again!
—*Elaine Chan*

To totally focus for a fairly long time—no distractions.
—*John Brothers*

Hacking the Body

Many respondents wanted to radically redefine biological limits by altering their brain's architecture, motor control, sensation or pain.



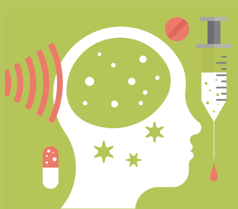
Much more energy. I could be another Marie Curie if I wasn't tired all the time!
—*Marilyn Miller*

Control involuntary bodily functions such as white blood cell count and appetite.
—*Eric Erwin*

The ability to see far beyond the human scope; to see in infrared and ultraviolet, darkness, and more.
—*Syona Fie*

The Sound of Healing

Focused ultrasound may help deliver drugs and other treatments



The brain is protected by formidable defenses. In addition to the skull, the cells that make up the blood-brain barrier keep pathogens and toxic substances from reaching the central nervous system. The protection is a boon, except when we need to deliver drugs to treat illnesses. Now researchers are testing a way to penetrate these bastions: sound waves.

Kullervo Hynynen, a medical physicist at Sunnybrook Research Institute in Toronto, and a team of physicians are trying out a technique that involves giving patients a drug followed by an injection of microscopic gas-filled bubbles. Next patients don a cap that directs sound waves to specific brain locations, an approach called high-intensity focused ultrasound. The waves cause the bubbles to vibrate, temporarily forcing apart the cells of the blood-brain barrier and allowing the medication to infiltrate the brain. Hynynen and his colleagues are currently testing whether they can use the method to deliver chemotherapy to patients with brain tumors. They and other groups are planning similar trials for patients with other brain disorders, including Alzheimer's disease.

Physicians are also considering high-intensity focused ultrasound as an alternative to brain surgery. Patients with movement disorders such as Parkinson's disease and dystonia are increasingly being treated with implanted electrodes, which can interrupt problematic brain activity. A team at the University of Virginia hopes to use focused ultrasound to deliver thermal lesions deep into the brain without having patients go under the knife.

"Using ultrasound to make lesions in the body is not a new concept; however, it's been limited for the brain because of the contours, density and thickness of the skull," says neurologist and study investigator Binit Shah. The new technique overcomes that hurdle by training more than 1,000 beams onto a target area. Shah and his colleagues' pilot study of patients with essential tremor—a common, usually benign condition of rhythmic shaking—was published in the *New England Journal of Medicine* last year and found that ultrasonic lesioning of part of the thalamus decreased tremor. The group is expanding the trial and launching other pilot studies to explore several symptoms of Parkinson's.

The benefits of focused ultrasound might extend well beyond restoring mobility and delivering drugs. Other groups are exploring its use in treating neuropathic pain and obsessive-compulsive disorder, too. —*Bret Stetka*

Hitting Just the Right Neurons

Noninvasive fields zap specific areas

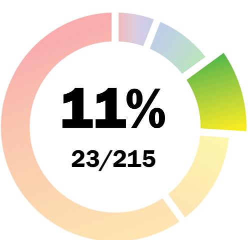
Electric and magnetic fields have been gaining ground as brain therapies because they can exert force on charged objects, such as neurons. Yet they typically affect cells indiscriminately, including healthy ones. Now researchers are looking to aim the fields more precisely to treat brain cancer and major depression.

People with dyslexia can exhibit certain visual talents not seen in people without the disorder. | When people with asthma believe they smell an irritant, their master a subject such as mathematics, music, science or foreign languages. Research already hints that strategically altering the firing patterns of neurons can enhance learning. For now such approaches are gaining the most ground in medical uses [see "Hitting Just the Right Neurons," below], but similar techniques could also rev up creativity and focus. To learn more about this topic, turn to page 56 for "Your Electric Pharmacy."

Finally, no survey of brain-upgrade fantasies would be complete without a few proposals that draw inspiration from science fiction. Two readers requested thought recorders to play back their inner monologues. Others suggested neural links to the Web for faster information browsing. Another reader wished for a switch that could unite all people's minds in cosmic consciousness to avert humanitarian crises. Such notions may seem farfetched, but real-world research continues to astound us with strange but true technology. For instance, tongue stimulation is restoring mobility to patients with neural damage [see "A Shock to the Tongue," below]. We can only stay tuned to see what mental plug-ins and power-ups come next.

—The Editors

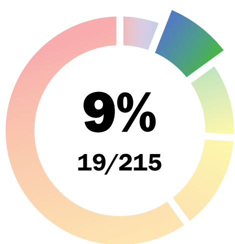
Building Character



Several proposals were high-minded, such as conquering vice or boosting grit and social graces.

Change some of the darker aspects of the brain. Midnight snacking, addiction to TV, the Internet and some other nastier things!
—Ambarish Ghatpande

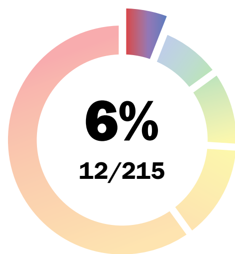
Going for Broke



Visions of cyborgs, telepathic communication, and science-fiction-inspired implants were frequent entries.

Wire me into the iCloud to selectively access huge amounts of information.
—Ernie Birge

Curing Disease



Some readers requested treatments for mental illness and brain diseases.

Revitalize receptors in Alzheimer's, sociopathy and other conditions. I imagine a more peaceful world as a result.
—Carmen Bailey

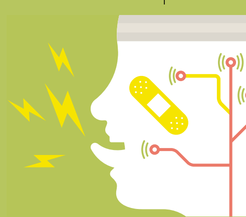
In 2011 the U.S. Food and Drug Administration approved a portable cap that delivers low-intensity, alternating electric fields to tumors in adults with recurrent glioblastoma multiforme, the most common and stubborn form of brain cancer. Rapidly dividing cancer cells have a unique electrical charge and shape, which allows the electric fields to single them out. By dismantling cell-copying machinery, the fields ultimately goad tumor cells into suicide. The technology is now being tested on other types of tumors, including those that appear in meningioma (cancer of the brain's lining) and lung cancer.

Another emerging technique also seeks to hit only desired targets, this time to treat major depression. Still highly experimental, magnetic seizure therapy (MST) showers certain brain areas with strong, rapidly alternating magnetic fields, provoking chemical changes in neurons that cause them to fire simultaneously and induce a seizure. The goal is the same as with electroconvulsive therapy (ECT), colloquially known as shock therapy; for unknown reasons, sparking electrical activity in the cortex relieves symptoms of depression. ECT, however, hits a larger swath of tissue and may cause memory loss and other bad side effects as the seizures spread through the brain. Researchers hope the more localized MST will one day replace ECT.

—Julia Calderone

A Shock to the Tongue

Electrically stimulating the tongue may help repair neural damage



A little-known fact: the tongue is directly connected to the brain stem. This anatomical feature is now being harnessed by scientists to improve rehabilitation.

A team at the University of Wisconsin–Madison recently found that electrically stimulating the tongue can help patients with multiple sclerosis (MS) improve their gait. MS is an incurable disease in which the insulation around the nerves becomes damaged, disrupting the communication between body and brain. One symptom is loss of muscle control.

In a study published in the *Journal of Neuro-Engineering and Rehabilitation,* Wisconsin neuroscientist Yuri Danilov and his team applied painless electrical impulses to the tip of the tongue of MS patients during physical therapy. Over a 14-week trial, patients who got tongue stimulation improved twice as much on variables such as balance and fluidity as did a control group who did the same regimen without stimulation.

The tongue has extensive motor and sensory integration with the brain, Danilov explains. The nerves on the tip of the tongue are directly connected to the brain stem, a crucial hub that directs basic bodily processes. Previous research showed that sending electrical pulses through the tongue activated the neural network for balance; such activation may shore up the circuitry weakened by MS.

The team is also using tongue stimulation to treat patients with vision loss, stroke damage and Parkinson's. "We have probably discovered a new way for the neurorehabilitation of many neurological disorders," Danilov says.

—Esther Hsieh

airways become inflamed, even when the odor is harmless. | Allowing children to act out the meaning of sentences can double reading comprehension.

Me vs. We How our culture and prosperity mold our beliefs about community

Kids These Days Really Are More Egocentric

But coming of age during a recession could temper that rising trend

MÁGOZ

Each generation thinks the next one is more self-centered. A recent study published in *Personality and Individual Differences* supports this perception: American society has steadily become more egocentric since the nation's beginnings. An overall rise in economic prosperity may play a role in this egotism, according to a different study: people who were young adults during hard times are less narcissistic than those who came of age during economic booms.

To measure trends in egocentrism, researchers at the University of Michigan analyzed the text of State of the Union Addresses from 1790 to 2012. They calculated an "egocentricity index" for each speech by comparing the number of words that indicated self-interest (such as "me," "we" or "mother") with the number of words that showed high levels of interest in others (such as "he," "neighbor" or "friend"). Not only did they find a steady increase in the use of self-interest words in the annual speeches over time, their analysis also revealed that before 1900, the speeches almost always used more other-interest words. After 1920, nearly every speech used more self-interest words.

To see if a president's speeches reflect egotism in American society at large, the team compared its results to studies of egotism in other cultural products, such as 20th-century books and songs. The researchers found rising egotism across the board. "This result tells me it's bigger than just a president," says Sara Konrath, a co-author of the paper and a professor at the Institute for Social Research at Michigan.

In a related but independent study published in July in *Psychological Science,* Emily Bianchi, a professor at Emory University's Goizueta Business School, looked at how the state of the nation's economy affected individual levels of narcissism. Bianchi used two types of personality tests to measure the narcissism of 32,632 participants aged 18 to 83. She found that people who were between 18 and 25 years old during hard economic times, as measured by unemployment rates, were less narcissistic later in life than those who came of age during economic booms. The same was not true for other age groups. Bianchi reasons that the difference exists because early adulthood is formative. Inexperienced employees are the most vulnerable during a recession; how much one struggles to establish a professional identity has a lasting impact.

In the final part of her study, Bianchi looked at CEO compensation relative to other executives. "It's a well-validated indicator of narcissism," Bianchi explains. "A CEO has control over how much the second most senior person gets paid." Using data from 2,095 CEOs, she found that those who were emerging adults during economic booms had a compensation that was 2.3 times higher than their second top executive, versus a difference of 1.7 for those who came of age in less prosperous times. As such, she believes the recent recession of 2008 and 2009 and its lasting effects on the job market will probably temper narcissistic tendencies in today's young adults—a dip in an overall rising trend. —*Esther Hsieh*

Holistic Thinking from Rice Farming

Historical agriculture practices predict modern mentalities

Often we view Chinese culture through an East versus West lens. But joint research from the U.S. and China indicates that northern Chinese may have a mind-set closer to individualistic Americans than their southern compatriots. And the reason is rice.

The Yangtze River splits China into north and south and serves as an agricultural and cultural divide, explains University of Virginia doctoral candidate Thomas Talhelm, first author of the study, which

M In people with dementia, music can reawaken memories and soothe agitation. Incorporating music into therapy might allow patients to avoid

Some Nice Guys Finish First

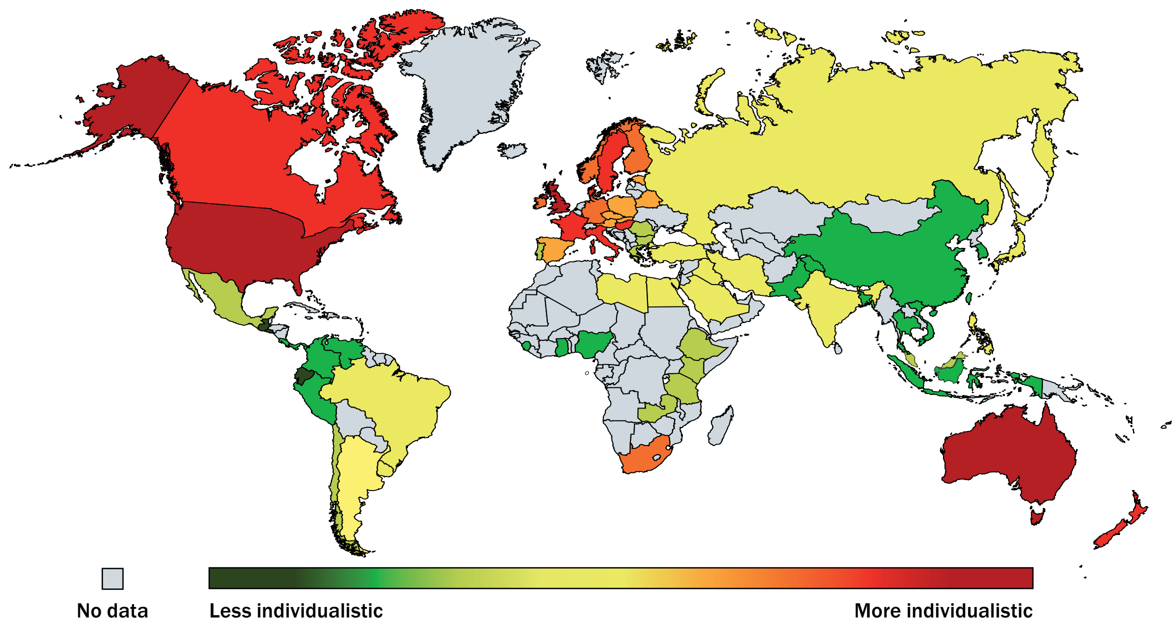
Warmth, not ability, earns professional status in collectivist societies

In the U.S., it is a given that those who are good at what they do earn status—respect, prestige, admiration. Being nice comes second. But that is not true everywhere. Different cultures have different values, and to climb the social ladder, you have to embody those values. In a recent paper in *Organizational Behavior and Human Decision Processes,* Carlos Torelli, a marketing professor at the University of Minnesota, compared the influence of individualism and collectivism on notions of status. He and his collaborators found that European-Americans were more likely than Latin Americans to demonstrate competence—for instance, solving tough problems at work—as a strategy for earning professional respect, whereas Latin Americans were more likely to demonstrate warmth, perhaps by volunteering to help co-workers.

Further, people who are individualist see status as a sign of competence but not warmth, whereas people who are collectivist associate warmth but not competence with status. Failing to recognize these cultural differences can create conflict and disappointment if, for instance, you and your superior are using different metrics to judge your performance.

"This stream of research is rooted in my observations about differences in politicians in Latin America and the U.S.," Torelli says. In the U.S., candidates often run on their business chops—Mitt Romney and Michael Bloomberg fit this mold. But in Latin America, he observes, "populist leaders are often idealized as selfless benefactors who genuinely care for the well-being of their people—think Salvador Allende or Hugo Chávez." —*Matthew Hutson*

Where the Selfish People Are



ISTOCKPHOTO (*map*); SOURCE: "CULTURE, INSTITUTIONS AND THE WEALTH OF NATIONS," BY YURIY GORODNICHENKO AND GERARD ROLAND. WORKING PAPER 16368. NATIONAL BUREAU OF ECONOMIC RESEARCH, SEPTEMBER 2010

appears in *Science.* Farmers north of the Yangtze predominantly grow wheat, and those to the south grow rice. Cultivating rice is very labor- and water-intensive, and it therefore requires sharing resources. Communities have to cooperate to plant and irrigate. Growing wheat requires half the labor and depends more on rainfall patterns, so it can be managed with much less reliance on one's neighbors.

Talhelm wondered if agricultural practices could help explain the more individualistic, or Western, mind-set he found in the north compared with the more holistic, or Eastern, way of thinking in the south. To investigate his "rice theory," Talhelm's team tested 1,162 students from 28 provinces in China for holistic thought, implicit individualism and loyalty. As expected, the researchers found that holistic thought and loyalty were higher in provinces with rice cultivation and that individualism was more common in wheat-farming areas. To see if the rice theory applied beyond students, the researchers also looked at provincial divorce rates, another indicator of individualism. "Wheat regions had a 50 percent higher divorce rate than rice regions," Talhelm says.

The rice theory jibes with other cultural research into how agriculture influences thinking, explains Richard Nisbett, a professor of psychology at the University of Michigan, who was not involved in the study. For example, Nisbett found that in Turkey, farmers (an interdependent occupation) were much more holistic than herders (an independent occupation). The new results add to our growing understanding that a region's agricultural history may have a lasting influence on its modern citizens' mind-set. —*Esther Hsieh*

the need for antipsychotic drugs. | Childhood stress can decrease the size of brain structures involved in learning, memory and emotional processing.

Exercise Counteracts Genetic Risk for Alzheimer's

Regular physical activity may correct the brain's metabolism to stave off dementia

If you carried a gene that doubled your likelihood of getting Alzheimer's disease, would you want to know? What if there was a simple lifestyle change that virtually abolished that elevated risk? People with a gene known as *APOE* e4 have a higher risk of cognitive impairment and dementia in old age. Even before behavioral symptoms appear, their brains show reduced metabolism, altered activity and more deterioration than those without the high-risk gene. Yet accumulating research is showing that carrying this gene is not necessarily a sentence for memory loss and confusion—if you know how to work it to your advantage with exercise.

Scientists have long known that exercise can help stave off cognitive decline. Over the past decade evidence has mounted suggesting that this benefit is even greater for those at higher genetic risk for Alzheimer's. For example, two studies by a team in Finland and Sweden found that exercising at least twice a week in midlife lowers one's chance of getting dementia more than 20 years later, and this protective effect is stronger in people with the *APOE* e4 gene. Several others reported that frequent exercise—at least three times a week in some studies; up to more than an hour a day in others—can slow cognitive decline only in those carrying the high-risk gene. Furthermore, for those who carry the gene, being sedentary is associated with increased brain accumulation of the toxic protein beta-amyloid, a hallmark of Alzheimer's.

More recent studies, including a 2012 paper published in *Alzheimer's & Dementia* and a 2011 paper in *NeuroImage,* found that high-risk individuals who exercise have greater brain activity and glucose uptake during a memory task compared with their less active counterparts or with those at low genetic risk.

This link to metabolism may help explain why exercise protects *APOE* e4 carriers. According to a theory proposed in May by anthropologist David Raichlen and psychologist Gene Alexander, both at the University of Arizona, the answer lies in our evolutionary past. Two million years ago, when our ancestors were much more physically active—for example, perhaps running long distances to hunt prey—only the high-risk gene variant existed, they argue. The gene allowed for better metabolism during intense activity, and its downside, faster cognitive decline, was counteracted by our ancestors' active way of life. As humans adopted more sedentary habits, other variants of the gene appeared, and in modern times we are now seeing the negative effect of the high-risk gene more often than its benefit.

Although these studies suggest that exercise is exceptionally protective for those at highest risk, some findings buck the trend. One large-scale study reported that high levels of leisure-time activity reduced risk of dementia five years later but only in those who did *not* carry the high-risk *APOE* e4 gene. These inconsistencies suggest the interaction may be complex, although most of the evidence still indicates that an active lifestyle has great value.

Exercise is important for healthy aging, regardless of genetics, but Raichlen emphasizes that "for individuals that are *APOE* e4 carriers, studies certainly underline the importance of maintaining physical activity across the life span." And with further research, he suggests, "a better understanding of the evolutionary origins of genotype-lifestyle interactions will help identify populations that may particularly benefit from behavioral changes." —*Emilie Reas*

Practice Doesn't Always Make Perfect

Science does not bear out the popular idea that nearly anyone can succeed with enough practice

It takes many thousands of hours of hard work to get to the top—yet time alone is not enough if you lack the other attributes necessary in your discipline, according to a study published online in July in *Psychological Science.*

In 1993 psychologist K. Anders Ericsson and his colleagues argued that success was not a matter of talent but rather what they termed deliberate practice, an idea that Malcolm Gladwell popularized as the "10,000-hour rule" in his book *Outliers.* Still, the role of deliberate practice—activities designed with the goal of improving performance—remained controversial. To try to sort things out, psychologist Brooke N. Macnamara of Princeton University and her colleagues reviewed 157 experimental results connecting total time spent practicing to ability in sports, music, education and other areas. On average, practice time accounted for just 12 percent of the variation in performance. Practice had the biggest effect on games such as chess—it explained 26 percent of the differences in performance—but it had almost nothing to do with ability in academic classes or professions, such as computer programming. The more rigorously each study judged its subjects' ability—such as by having experts evaluate their performance—the less total practice time mattered.

Although the authors wrote that they could not yet be sure what other factors contribute to high-level ability besides practice, they thought natural talent, general intelligence and working memory most likely play important roles. And success, of course, does not always scale with performance—getting to the top also depends on personality, determination and simply being in the right place at the right time. —*Nathan Collins*

THINKSTOCK (*hoop user*); JASON LEE (*batter*)

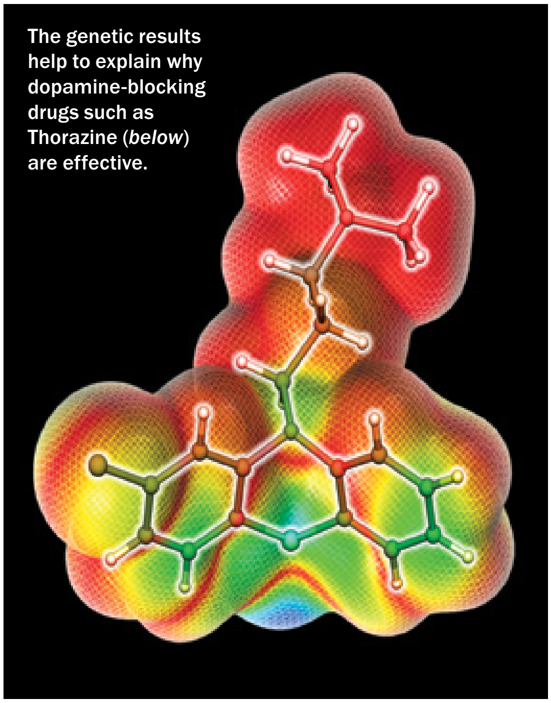
M A brain rhythm called a gamma wave may underpin our ability to identify and become curious about new things. | Sleep-deprived individuals

Schizophrenia's Genetic Roots

The largest-ever genetic study of mental illness reveals a complex set of factors

Schizophrenia is a distressing disorder involving hallucinations, delusions, paranoia and agitation. It affects around one in 100 people in the U.S., with symptoms usually first appearing between the ages of 16 and 30. Its causes have long been debated, particularly regarding whether genetics plays a role. It is known to be highly heritable, but small sample sizes and other methodology hurdles stymied early attempts to discern a genetic link.

Now the biggest-ever genetic study of mental illness has found 128 gene variants associated with schizophrenia, in 108 distinct locations in the human genome. The vast majority of them had never before been linked to the disorder. This finding lays to rest any argument that genetics plays no role.



The genetic results help to explain why dopamine-blocking drugs such as Thorazine (*below*) are effective.

PASIEKA *Science Source*

The study, published in July in *Nature,* is the result of a collaboration among more than 300 scientists from 35 countries, named the Schizophrenia Working Group of the Psychiatric Genomics Consortium. The researchers compared the whole genomes of nearly 37,000 people with schizophrenia with more than 113,000 people without the disorder, in a so-called genome-wide association study (GWAS). Genetic material, or DNA, is made up of a sequence of molecular pairs, thousands of which string together to form genes. The GWAS involves tallying known common mutations in these pairs, in people with and without a condition. Variants that show up significantly more often in people with the condition are said to be "associated" with it. The GWAS "potentially provides a more comprehensive view of the biological players in disease than previous genetic studies," says Benjamin Neale of the Broad Institute in Cambridge, Mass., one of the study's lead authors.

The technique cannot identify the exact mutations that cause illness or even pinpoint specific genes. Rather it flags areas of the genome that contribute to risk. Genes in these regions warrant further investigation to uncover the biological processes underlying the condition. "We've prised open lots of windows for people to climb in and attack the biology of schizophrenia," says Michael O'Donovan of Cardiff University in Wales, another lead author.

Treatments for schizophrenia have not advanced in more than 50 years, since the discovery of drugs that reduce the activity of the chemical messenger dopamine. A leading theory has therefore focused on overactive dopamine signaling. Sure enough, one of the identified regions contains a gene that produces the type of dopamine receptor that is blocked by antipsychotic drugs.

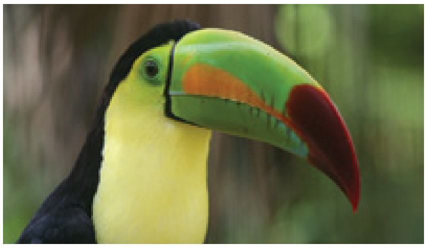
Another of the brain's chemicals, glutamate, has also received attention, but drugs that target it have not fared well in clinical trials. The new study implicated several glutamate-related genes. "This is important confirmatory evidence that glutamate is relevant to schizophrenia," O'Donovan says. "Exactly how is another question." Past drugs may have failed because, for instance, they targeted the wrong kind of glutamate receptor; the genetic results will help drug developers focus their efforts.

The meaning of some of the other findings is less clear. Immune system genes were implicated, as were genes previously associated with smoking. These findings do not necessarily mean that schizophrenia is related to immunity or that smoking causes schizophrenia. The area of the genome related to immunity contains hundreds of genes, some of which affect other aspects of biology. Genes can also perform distinct roles in various tissues. "A lot of immune system proteins probably have different functions in the brain," O'Donovan says. The link with smoking is similarly opaque. For instance, one genetic variant might both predispose people to smoking and increase the risk of schizophrenia, without one causing the other.

An important overall conclusion is that schizophrenia is a complex trait like any other, but its complexity does not mean it will remain mysterious. Past GWAS research has led to breakthroughs for other health conditions with tangled genetic and environmental roots, such as diabetes and Crohn's disease, and experts believe that this study will do the same for schizophrenia. "That there are lots of small, common genetic effects, scattered across the genome, is itself an important finding," Neale says. "There are many different biological processes involved." —*Simon Makin*

are more likely to form false memories than the well rested. | Western scrub jays are capable of metacognition, or thinking about thinking.

Unwind amidst the natural and cultural landmarks of the Maya world. Join Bright Horizons 24 as we mingle contemporary science and the many cultures, past and present, of Mexico, Honduras, and Guatemala. Explore the beautiful and compelling monuments of the ancient Maya world, and meet the modern Maya people. Experience Central America's Afro-Caribbean culture. While aboard ship, we'll discuss the latest discoveries and wonders of science. Relax with water sports and encounter the UNESCO World Heritage Site Quirigua. Special memories, great lifelong learning, and the simple pleasures of a warm, sunny getaway await you on Bright Horizons 24. Make your reservation today!



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Lightning

Speaker: Joseph R. Dwyer, Ph.D.

The Mysteries of Lightning

While lightning is one of the most widely recognized natural phenomena, it remains poorly understood. Learn what we do and don't know about lightning, including the recent discovery that lightning emits bursts of x-rays and gamma-rays. By measuring these high-energy emissions, researchers are gaining a better understanding of this fascinating phenomenon.

Ball Lightning

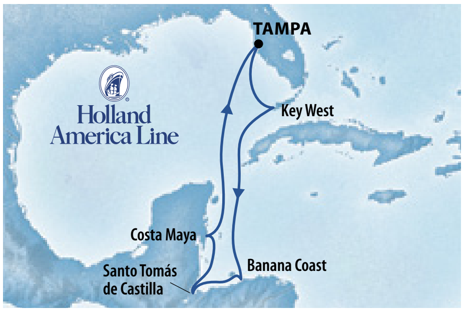
Ball lightning has been reported by eyewitnesses as a grapefruit-sized glowing sphere as bright as a 60-watt light bulb, often seen along with thunderstorms. Yet little is known about ball lightning, and it has never been replicated in the lab. We'll discuss amazing reports of ball lightning and some of the latest explanations.

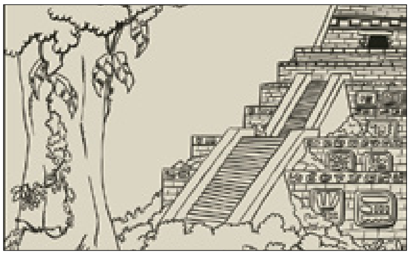
Sprites, Pixies, and Other Atmospheric Phenomena

Although we spend our entire lives inside our atmosphere, there are surprisingly many things that we don't know about the air right over our heads. Learn about strange discharge phenomena dubbed sprites, elves, trolls, pixies, and gnomes, and other amazing atmospheric curiosities.

Lightning Safety

Lightning strikes our planet about 4 million times every day, causing billions of dollars in property damage and killing or injuring many people each year. Despite the dangers, many people don't know how to be safe during thunderstorms. Learn about the harmful effects of lightning, along with lightning protection and safety.





The Maya

Speaker: Joel Palka, Ph.D.

Archaeological Highlights of Maya Civilization

From over a century of excavations in Mexico and Central America, we understand when Maya society formed, how their cities flourished in the tropical forests, and how they lived their daily lives, yet some mysteries of the Maya remain. We'll overview this fascinating civilization and some of the questions we still have.

Maya Hieroglyphic Writing for Everyone

Maya hieroglyphs present exciting details on ancient Maya life including religion, politics, trade, and the organization of society. We'll cover the deciphering of Maya writing, the structure of the texts, and basic knowledge of Maya culture through their hieroglyphs.

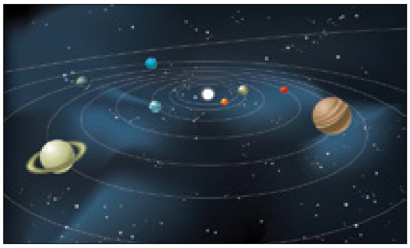
Native Maya Perspectives of the Sea

For many of us the sea represents beauty and wonder, but how did indigenous Maya people

For more info please email Concierge@InsightCruises.com or visit ScientificAmerican.com/travel view the sea? We'll focus on Maya culture and the sea as seen in painted pottery, monumental sculpture, and colonial-era narratives.

Maya Pilgrimage to Ritual Landscapes

Recent archaeological and anthropological findings have shed new light on ancient Maya travel, religion, and views of the landscape. Islands, mountains, caves, and lakes made up sacred places to them. This session looks at the latest interpretations of ancient Maya pilgrimage, their ritual landscapes, and how these were central to Maya society.



Our Solar System

Speaker: Adriana C. Ocampo, Ph.D.

Cosmic Collision: The Search for the Dinosaur Killer

Around 65 million years ago a massive space rock hit Central America, setting off a biospheric disaster that wiped out the dinosaurs. Take a voyage back in time, via Belize and neighboring Mexico, to explore the impact site of the ancient asteroid that drastically altered the balance of life on Earth.

Our Neighborhood in the Solar System

In this extraordinary time for planetary science we are beginning to understand planetary formation processes that were wholly unknown to us just a short time ago. Guided by the latest scientific insights, we'll discuss how planets form, why asteroids and comets are important, and whether habitable environments exist beyond Earth.

Exploring our Solar System

NASA's robots have now taken us out to 180 astronomical units (AU), or about 180 times the distance from Earth to the Sun. We'll delve into some of their fascinating discoveries, such as the similarities and differences between the gas giant planets and the key role Jupiter plays for Earth.

Neuroscience

Speaker: Lary C. Walker, Ph.D.

Life and its Discontents

Disease is an inescapable fact of life, but our very existence is shaped by our relationship with potential disease agents. We'll explore the biological origins of disease to understand why the brain is vulnerable to a distinctive constellation of disorders as we age.

Scratching Sheep, Mad Cows, and Laughing Death

Follow the incredible scientific odyssey that began in the 18th century with a mysterious disease of sheep and, in the 20th century, bore two Nobel Prizes. Learn about the prion, an infectious protein and possibly the most controversial molecule in the history of medicine.

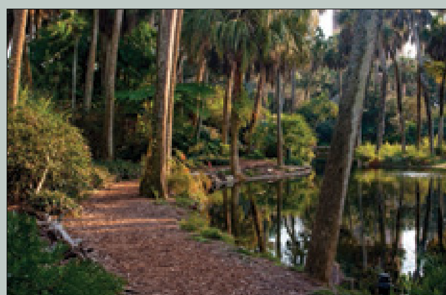
Why Old Brains Falter

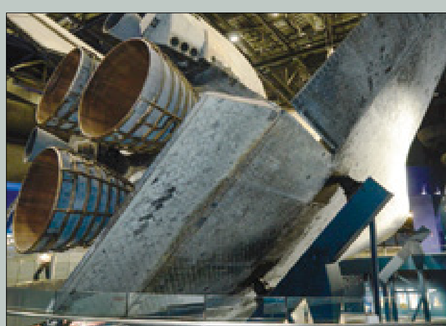
One of the most feared diseases of old age is Alzheimer's disease, the most frequent cause of dementia. Learn how the brain changes in normal aging and in Alzheimer's disease, how Alzheimer's emerges and spreads within the brain, and why it is so difficult to stop.

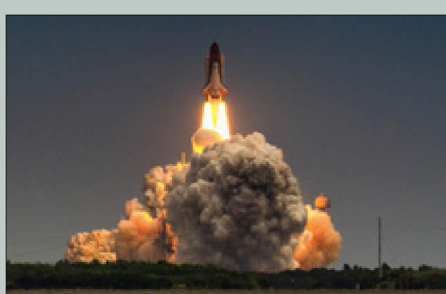
Alzheimer's Therapies: Hype and Hope

No current treatment can stop the relentless progression of Alzheimer's disease. We'll explore the history of rational therapeutic approaches to Alzheimer's and take a frank look at the benefits and shortcomings of existing treatments. Finally, we'll consider how our growing knowledge of brain aging offers hope that an effective therapy is possible.

SCIENTIFIC AMERICAN Travel HIGHLIGHTS OUTER SPACE AND OPEN SPACE IN FLORIDA







BOK TOWER GARDENS: Sunday, March 22, 11am – 4pm

KENNEDY SPACE CENTER (KSC): Monday, March 23, 8am – 7:30pm

Continue the Bright Horizons fun with a two-day exploration of two very different central Florida gems: Bok Tower Gardens and Kennedy Space Center.

Bok Tower Gardens — a National Historic Landmark botanical garden and bird sanctuary — is an opportunity to relax amidst subtropical landscape gardens which help preserve 64 rare Central and North Florida plant species. We'll also hear the Garden's 60-bell carillon play.

Reconnect with the spirit and substance of space exploration on our visit to Kennedy Space Center. Guided by tour specialists, explore the world's largest launch facility.

First stop: Launch Control Center. Journey inside the firing room where the last 21 shuttle launches were controlled. Pass by the computer consoles at which engineers constantly monitored the launch controls. See the launch countdown clock and large video monitors on the walls. Enter the bubble room with its wall of interior windows through which the management team viewed all of the proceedings below. Re-live the last shuttle launch, Atlantis mission STS-135 (see takeoff photo, below), while watching the launch footage in the room where the launch became part of history.

Get the right stuff at lunch as we meet a veteran member of NASA's Astronaut Corps, have a hot buffet lunch, and participate in a 30-minute interactive Q&A during "Lunch with an Astronaut."

Onward to the Space Shuttle Atlantis, along with the interactive exhibits that bring to life the complex story of the shuttle and the thousands of people who created and maintained it.

Join us for a memorable look at KSC's role in the endeavor of exploration.

Price: $899 per person, based on double occupancy; $1,399 for a single. Kennedy Space Center launch facilities are transitioning to commercial missions and are under construction. Therefore the structures and vantage points we experience and the entire sequence of our day are subject to change. Regardless of our tour route, we will have an excellent tour of KSC!

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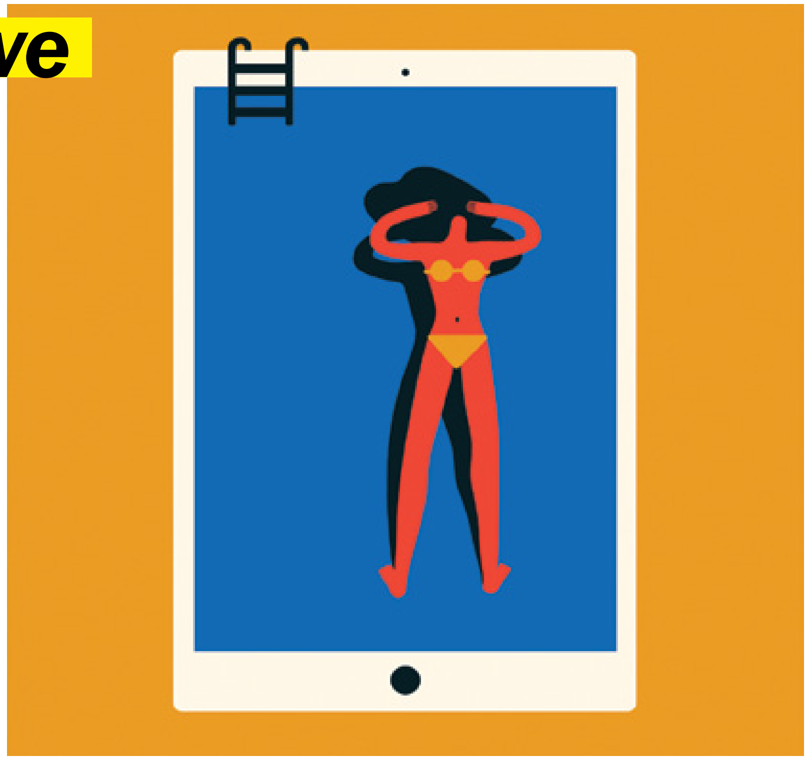
A GUIDE TO MASTERING YOUR WORLD

How to Be a Better **digital native**



The other morning I found myself getting really agitated. Not because my three-year-old was whining or because I was behind on a deadline—no, I was antsy because there were *no new posts* in my Facebook feed. I had been constantly checking my phone during a rare stretch of free time and found myself jonesing for another "hit" of digital input. *Dislike.* I want digital technologies to take stress and brain strain out of my life, not add more. You, too? Here's how psychology and neuroscience experts say we can use tech to improve our mental health rather than allowing its ubiquity to mess with our minds.

#1 Stare at some nature on-screen. It's pretty well established that being in nature is invigorating for mind and body. Even just seeing nature out of a window has been found to help people in hospitals heal better from surgery. "What recent studies are showing us is that if you don't have access to the outdoors but need to boost your mood or drop your level of stress, you can get a quick fix by looking at digital nature—a movie or photos," says Jenny Fremlin, a media psychologist and app developer in Douglas, Alaska. There are a ton of free "nature" wallpapers for your phone or computer desktop out there; plenty are probably built into your computer or smartphone's operating system, and *National Geographic* has some beauties at photography.nationalgeographic.com.

#2 Trade in your Scrabble app for Call of Duty. The idea that doing crossword puzzles or Sudoku can keep your mind sharp as you age has been mostly debunked. What *can* improve cognition? First-person shooter video games such as Halo or Modern Warfare. Seminal studies by cognitive neuroscientist Daphné Bavelier of the University of Geneva and her colleagues have found that playing fast-paced action games can improve vision, increase attention, sharpen multitasking abilities and speed decision making. "As a brain scientist, I'm most surprised by the fact that players don't just become better at playing video games—it translates to other skills that we don't typically think would be related," Bavelier says. "Video games have been totally trivialized, but they clearly have effects that are not trivial." For increasing attention and vision, Bavelier has found that the best regimen is about 35 to 50 minutes a day. If you're like me and blasting bloody holes in virtual enemy soldiers isn't really your thing, stay tuned: Bavelier and other researchers are hard at work developing nonviolent games that challenge the same brain pathways.

#3 Realize phone fun is like a drug. Seventy-one percent of all social networking takes place on mobile phones these days, as does 86 percent of gaming and 90 percent of instant messaging, according to the analytics experts at ComScore. And there's a good reason why so many of us are constantly tapping on our cell-phone screens. Research suggests that using social media, video games and other digital technologies may provide a druglike hit of pleasure for users, says Tomas Chamorro-Premuzic, a professor of business psychology at University College London, who studies media and consumer preferences. "Studies show there is a firing up of dopamine-related neurotransmitters. That means your brain is experiencing the interaction as highly pleasurable and responds with an intense need to do it," Chamorro-Premuzic says.

#4 Practice purposeful moderation. Mobile technology is like anything else, it seems: fine in moderation. "If you are habitually checking e-mail or picking up your phone looking for alerts that haven't sounded, you'll feel drained," Fremlin says. "Pay attention to what you're doing, how it affects you and how it relates to other things in your life. Make your technology use and online interactions purposeful." To keep myself in that moderate zone, I've moved Facebook off my phone's home screen. It now takes a swipe and two taps to fire it up, and so far that's enough of a barrier to slow down the mindless checking. If I find myself jonesing again, I'll lay down the law and make Facebook a once- or twice-a-day treat. —*Sunny Sea Gold*

PAUL PANTAZESCU *iStockphoto (globe icon)*; MÁGOZ *(swimmer)*

M Having someone convince you that you got a good night's rest, when you in fact did not, can ward off the negative effects of lost sleep.

Afraid of Solitude

Many people prefer any activity to simply sitting quietly—even an electric shock

MARGHERITA CECCHINI *age fotostock*

"All of humanity's problems stem from man's inability to sit quietly in a room alone," said French philosopher and mathematician Blaise Pascal in the mid-17th century. The sentiment may be truer today than ever, according to a paper published July 4 in *Science*. Researchers asked participants to rate how much they enjoyed being in a room with nothing to do. Of 409 participants, nearly half said that they did not like the experience. When asked to do the same at home for six to 15 minutes, a third said that they had cheated.

In one telling experiment, each of 55 participants was seated alone in a quiet, empty room with nothing to do—except they had access to a button that would deliver an electric shock to their ankle which they had previously described as "unpleasant." In their 15 minutes of solitude, 67 percent of the men and 25 percent of the women chose to shock themselves instead of simply sitting quietly. Lead author Timothy Wilson, a University of Virginia psychologist, says that with smartphones, tablets and TVs within reach anytime, many of us may not know what to do when we have time to ponder without distraction—but the electric shock results were still surprising. He suggests we could make our downtime—even traffic jams and waiting rooms—more relaxing and interesting by learning how to be alone with our thoughts.

"I suspect that practice helps, as does finding topics that you enjoy thinking about in detail and can return to time and again, so that you don't have to start from scratch each time," Wilson says. ***—Susan Cosier***

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Oceanography

Speaker: Harold Tobin, Ph.D.

Dynamics of the Mid-Atlantic Ridge

Iceland sits astride the Mid-Atlantic Ridge, where we can literally see Earth's crust forming. We'll discuss how the deep ocean basins have formed and evolved throughout Earth's history and place Iceland's young and volcanic geology in that context. You'll also learn how plate tectonics and the evolution of life are inextricably linked.

Exploring Undersea Earthquakes, Landslides, and Tsunami

In the past decade, the world has witnessed two enormously destructive tsunamis that have led to a mini-revolution in how we understand subduction zones, where the seafloor is consumed and returns to the Earth's mantle. We'll explore the nature and causes of submarine movement, from sediment flows to the largest landslides and earthquakes.

The Gulf Stream, North Atlantic Deep Water, and the Global Heat Conveyor Belt

Three basic ingredients control the ocean's movement: temperature, salinity, and the spin of the Earth on its axis. We'll examine how and why water moves in established cycles ranging from years to millennia, and how these currents and flows control the climate of the planet as a whole.

The Global Ocean, Climate Change, and Sea Level Rise

Sea level is rising at an accelerating pace, but, surprisingly, not at the same rate everywhere. We'll explore the science behind sea level, past and present, sea ice, ocean ecosystems, and past and future climate change.

Earth Science

Speaker: Bill McGuire, Ph.D.

The End of the World: Everything You Never Wanted to Know

How long can the human race survive? A major asteroid impact wiped out more than half of all life 65 million years ago, while a volcanic super-eruption 74,000 years ago may have brought our species to the brink of extinction. Learn about the prospects for similar threats in the future, along with giant tsunamis, megaquakes, and climatic mayhem.

The Biggest Bangs Since the Big One

Volcanic eruptions are arguably the most spectacular of all geophysical phenomena. They also have the potential to be the most devastating. Learn about recent mayhem-generating eruptions, such as the 2010 blast of Iceland's Eyjafjallajökull, and find out which volcanoes might be the next to go bang.

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How a Changing Climate Triggers Earthquakes, Tsunamis and Volcanoes

An astonishing transformation over the last 20,000 years has seen our planet flip from a frigid wasteland into the temperate world. Now there are signs that human-induced climate change is causing another turnaround. Could we bequeath to future generations not only a far hotter world, but also a more geologically fractious one?

Surviving Armageddon: Solutions For a Threatened Planet

Our world is constantly under threat, both from geological processes and from the cosmic forces that rage beyond our atmosphere. Can we use our scientific understanding and our technology to make the world a safer place? We'll discuss volcano monitoring, earthquake prediction, asteroid spotting and other efforts underway.

Architecture & Engineering

Speaker: Stephen J. Ressler, P.E., Ph.D.

A Field Guide to Great Structures

Many of the world's greatest works of architecture have been profoundly influenced by the principles of engineering mechanics that underlie their design. Learn how to see, analyze, and understand the many fascinating structures we will encounter during our cruise, from the Hallgrímskirkj in Reykjavik to the great bridges of the Norwegian fjords.

The Norwegian Stave Church

The stave church is a medieval building that was once common throughout northwestern Europe. Today the few surviving examples are found almost exclusively in Norway. Learn to see the stave church not just as an iconic architectural form, but as a sophisticated technological system as well.

Saint Paul's Cathedral: Evolution of the First Modern Dome

Learn about the development of the dome as a structural and architectural element from the Classical Era through the 18th century. We'll focus on the extraordinary structural innovations devised by Sir Christopher Wren for the dome of Saint Paul's, and we'll see how these innovations overcame the inherent structural limitations of earlier domes.

A Structural Retrospective

We'll examine interesting structures photographed by Bright Horizons participants during our trip, analyzing the structural system, discerning the underlying engineering principles, and assessing how structural considerations influenced the architectural design. Learn how your appreciation of great architectural works can be enriched through an understanding of basic structural mechanics principles.

Anthropology

Speaker: Kenneth Harl, Ph.D.

Why Was There a Viking Age?

Learn how the harsh climate and daunting geography of Scandinavia shaped the unique culture and religion of the Nordic peoples of the Viking Age. The Scandinavians produced superb ships, excelled in warfare, celebrated ancestral heroes and worshiped frightening gods. We'll look at how the many strands of Viking life tied together.

Viking Voyages of Discovery

Learn how Vikings braved the North Atlantic in spectacular voyages of discovery that led to the colonization of the Faroe Islands, Iceland, Greenland, and Newfoundland. Hear about the exploits of Erik the Red, Leif Eriksson and other Nordic explorers, their remarkable ships and seamanship, and the peculiar legacy of faked Viking artifacts from this time.

The Icelandic Republic: A Frontier Society

Learn how Icelanders created the first overseas European colonial society and established a remarkably successful form of government and a rich literary tradition. We'll examine records of family sagas to learn about the lives, loves and disputes of ordinary men and women in Viking Age Iceland.

Poetry and Saga of the Viking Age

Viking Age Icelanders developed a genius for reciting poetry and storytelling—skills prized for entertainment during the long winters. We'll read poems replete with subtle metaphors and composed in an array of alliterative verses, as well as prose narratives that stand among the finest vernacular literature of Medieval Europe.

Vikings in Hollywood

We'll take an entertaining look at novels, comics and movies that have popularized the image of barbaric Vikings sporting horned helmets. While it is easy to dismiss Hollywood for sensationalism, it is remarkable how well some examples have recreated the spirit of the Viking Age.

Neuroscience

Speaker: Martha J. Farah, Ph.D..

Cognitive Enhancement: the Neuroscience of Boosting Your Brainpower

Can a pill make you smarter? Hear the latest on the neural bases of intelligence and methods for enhancing it, including psychopharmacology, transcranial brain stimulation and "brain-training" programs. We'll also consider the ethical, legal, and societal impact of these practices.

Wellbeing and the Brain

Whatever wellbeing means to you, chances are the brain plays an important role in attaining and maintaining it. Learn about the neural bases of mood and resilience, and how exercise, sleep, social connectedness and meditation can improve these functions and the brain systems that support them.

Neurolaw

"Ladies and gentlemen of the jury, do not condemn my client for his actions. He had no choice in the matter; events set in motion at the time of the big bang resulted in his brain functioning as it did on that fateful day." Would you be persuaded by this lawyer's defense? We'll explore the fascinating intersection of ethics, law and neuroscience.

How Genes and Experience Make Us Who We Are

From prenatal processes of cell creation and migration in the fetal brain to the sculpting of neural connections in adolescence, human brain development is a complex and prolonged process. We'll discuss genetic influences on intelligence, personality and other reflections of brain function, and how each individual's life experiences influence the development and function of the brain.

SCIENTIFIC AMERICAN Travel HIGHLIGHTS LONDON (HARWICH)

Saturday, August 1st

Find your own version of London amidst its many layers and neighborhoods. Museums and parks, tradition and innovation, urban vitality and peaceful corners are all up for your exploration.

Vivid Dreams Comfort the Dying

Memorable visions at the end of life are more than just delirium

Right before dying, many people experience vivid and meaningful dreams and visions, according to accounts across cultures and throughout history. Yet little scientific research has investigated the phenomenon. A new study in the *American Journal of Hospice & Palliative Care,* the first study to focus primarily on the patient's perspective, found that most of these dreams are a source of personal comfort. They bring about a sense of peace, a change in perspective or an acceptance of death, suggesting that medical professionals should recognize dreams and visions as a positive part of the dying process.

Researchers at Daemen College and at Hospice Buffalo, an agency of the Center for Hospice & Palliative Care, studied 63 patients admitted to the hospice over a period of 18 months. Investigators interviewed patients daily, asking them about any dreams and visions and taking down detailed descriptions of them. Most participants reported experiencing at least one dream or vision, memorable in much more clarity than other dreams or delirious episodes and characterized by an impression of realism and emotional significance. The researchers' analysis revealed six categories that encompassed all the dreams—often participants saw deceased loved ones waiting for them, for example [*see box at right*]. As patients approached death, they tended to transition from dreaming about living people to dreaming about the dead, which the patients described as more comforting.

The overarching theme that emerged from the study was that end-of-life dreams and visions are a source of comfort. Previous studies have come to similar conclusions: a survey of hospice nurses in 2013 found that 89 percent believed these experiences were associated with calm and peaceful deaths. Yet medical professionals tend to discount predeath dreams and visions, according to physician Christopher W. Kerr, one of the study's co-authors. He says that most doctors offhandedly attribute these incidents to delirium or the side effects of medication.

The researchers believe that such a dismissive attitude toward dying patients' experiences can be detrimental to their mental health. "We need to treat the patient, not only the disease; overall quality of life at the end of life is important," says Pei C. Grant, director of research at Hospice Buffalo. She and her colleagues suggest that families and practitioners talk about dreams with patients—who are often excited to share their dreams when asked about them. Doing so allows patients to review their life, process feelings about death and come to terms with past experiences. "Just being there and listening—that's really what the patient wants," Grant says. Acknowledging the personal significance of these end-of-life experiences may help patients and families through the difficult transition from dying to death. —*Emma Badgery*

Visions of Lost Loved Ones

As patients approach death, they often have realistic and memorable dreams in one or more of these six categories, according to the new study:

- **1. Comforting presence:** A loved one—often deceased but sometimes living—offers solace.
- **2. Preparing to go:** Patients ready themselves for a journey. In one patient's dream, she boarded a plane with her (living) son and felt comforted.
- **3. Watching or engaging with the dead:** Deceased friends and relatives play a significant role, which patients overwhelmingly reported as being comforting.
- **4. Loved ones waiting:** Deceased friends often seem to be "waiting." Three days before her death, one woman reported both visions and dreams of being at the top of a staircase with her (predeceased) husband waiting for her at the bottom.
- **5. Distressing life experiences:** Patients may revisit traumatic life experiences, such as war, childhood abuse, or difficult situations or relationships.
- **6. Unfinished business:** A few patients report distressing dreams that center on fears of being unable to accomplish important tasks. Two young mothers recount dreaming about caring for their children. —*E.B.*

ALAMY

M Limiting children's screen time has been observed to have long-lasting effects on sleep, weight gain and performance in school.

Addicted to Tanning

UV light may trigger the same reward pathway in the brain as drugs such as heroin


ROMANO CAGNONI *Getty Images*

Experts have long wondered why many people tan regularly despite the known risk of skin cancer. Past studies suggest that the motivation is not just vanity—some tanning buffs have symptoms of dependence and withdrawal. Now a study in *Cell* adds more evidence that tanning is addictive. It showed that mice become dependent on beta-endorphin, a druglike opioid molecule made by the skin under ultraviolet light.

A team at Massachusetts General Hospital scrutinized the opioid system, the reward pathway hijacked by drugs such as heroin, because the researchers had earlier found that beta-endorphin and the skin pigment melanin originate from the same protein. Other studies have also pointed to the opioid system; in one, frequent tanners showed withdrawal symptoms when they took a drug that blocked opioid receptors.

In the new study, shaved mice got a daily dose of UV light long enough to tan but not burn—on a par with 20 to 30 minutes in midday Florida sun for a fair-skinned human. After a few days, levels of beta-endorphin rose in the mice's blood. Then the researchers rated pain tolerance, a marker of opioid dependence, using heat and touch. The UV mice had a pain threshold up to three times higher than mice that had not tanned. As levels of beta-endorphin rose, so did pain tolerance, suggesting the endorphin played a key role.

When the UV mice received an opioid blocker, their pain threshold reverted to normal, and they showed withdrawal symptoms such as shaking paws and chattering teeth. The mice even modified their behavior to avoid withdrawal: those that received opioid blockers in a dark box preferred to spend time in a white box, despite rodents' natural penchant for darkness.

Humans and mice share these chemical processes, so the researchers believe beta-endorphin may cause addiction in people. Getting sun may be rewarding to the brain because we need vitamin D, explains David Fisher, a co-author of the study and director of the melanoma program at Mass General. Next Fisher hopes to investigate whether this pathway is involved in seasonal affective disorder, possibly providing a new therapeutic target. —*Esther Hsieh*

(PHARMA WATCH)

ALL-PURPOSE ANTIDEPRESSANTS

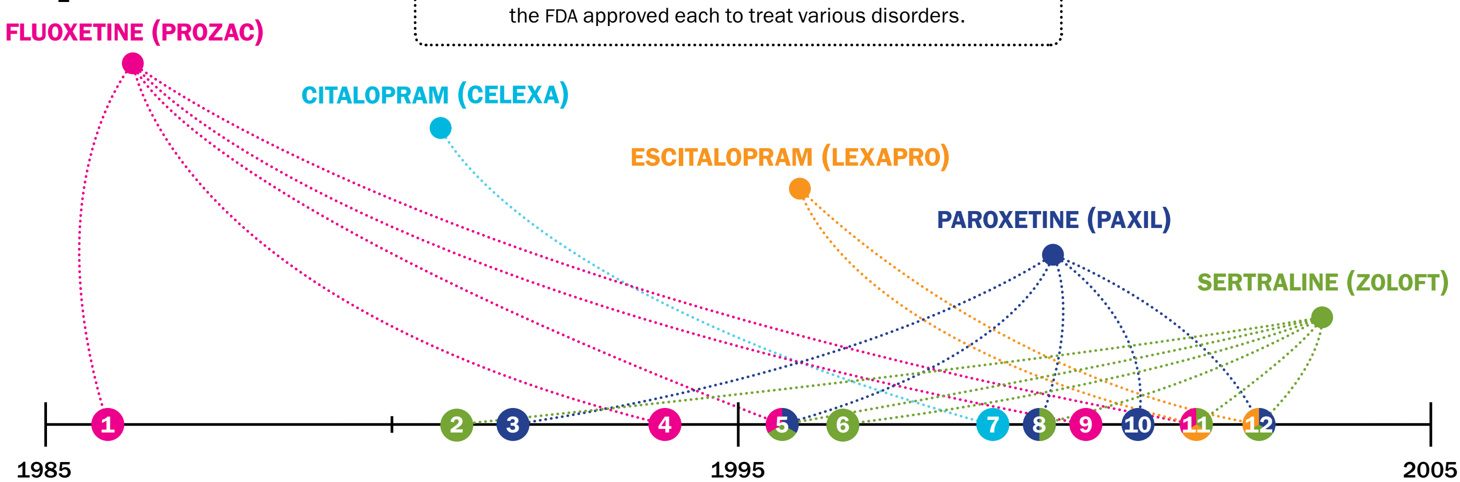
Doctors are increasingly prescribing SSRIs to treat more than just depression

Antidepressant use among Americans is skyrocketing. Adults in the U.S. consumed four times more antidepressants in the late 2000s than they did in the early 1990s. As the third most frequently taken medication in the U.S., researchers estimate that 8 to 10 percent of the population is taking an antidepressant. But this spike does not necessarily signify a depression epidemic. Through the early 2000s pharmaceutical companies were aggressively testing selective serotonin reuptake inhibitors (SSRIs), the dominant class of depression drug, for a variety of disorders—the timeline below shows the rapid expansion of FDA-approved uses.

As the drugs' patents expired, companies stopped funding studies for official approval. Yet doctors have continued to prescribe them for more ailments. One motivating factor is that SSRIs are a fairly safe option for altering brain chemistry. Because we know so little about mental illness, many clinicians reason, we might as well try the pills already on the shelf. —*Julia Calderone*

An Expanding Repertoire

Below are the five SSRIs approved in the U.S. and the dates the FDA approved each to treat various disorders.



1. Major depressive disorder
2. Major depressive disorder
3. Major depressive disorder
4. Obsessive-compulsive disorder
5. Bulimia nervosa; Obsessive-compulsive disorder; Panic disorder; Obsessive-compulsive disorder
6. Panic disorder
7. Depression
8. Social phobia (social anxiety disorder); Post-traumatic stress disorder
9. Premenstrual dysphoric disorder
10. Generalized anxiety disorder; Post-traumatic stress disorder
11. Panic disorder; Premenstrual dysphoric disorder; Major depressive disorder
12. Generalized anxiety disorder; Premenstrual dysphoric disorder; Social anxiety disorder

Common Off-Label Uses

Doctors commonly use antidepressants to treat many maladies they are not approved for. In fact, studies show that between 25 and 60 percent of prescribed antidepressants are actually used to treat nonpsychological conditions. The most common and well-supported off-label uses of SSRIs include:

- Abuse and dependence
- ADHD (in children and adolescents)
- Anxiety disorders
- Autism (in children)
- Bipolar disorder
- Eating disorders
- Fibromyalgia
- Neuropathic pain
- Obsessive-compulsive disorder
- Premenstrual dysphoric disorder

Investigational Uses

SSRIs have shown promise in clinical trials for many more disorders, and some doctors report using them successfully to treat these ailments:

- Arthritis
- Deficits caused by stroke
- Diabetic neuropathy
- Hot flashes
- Irritable bowel syndrome
- Migraine
- Neurocardiogenic syncope (fainting)
- Panic disorder
- Post-traumatic stress disorder
- Premature ejaculation

ISTOCKPHOTO (*pills*)

M Volunteering often gives people a "helper's high," or a boost in happiness. | For full stories: ScientificAmerican.com/Mind/nov2014/stories

Seeing Red

The facts and fictions of crimson perception

Red is a powerful color. It's the color of Cupid and the Devil, the color of love and hate. It brings to mind hot-blooded anger and *Scarlet Letter* shame. It means luck in China, where bridal wear is red, mourning in parts of Africa and sex in Amsterdam's red-light district.

Some of the hue's significance has a biological basis. Many humans get red in the face from increased blood flow when they are angry. A similar process activates a flush of embarrassment or a more flirtatious blush. Seeing red also triggers some surprising behaviors. For instance, drivers blocked in traffic by a red car react faster and more aggressively than drivers barred by vehicles of other colors.

Perhaps the most famous example of the pigment's power comes from animal perception. For hundreds of years matadors have taunted bulls by flashing a red cape. According to bullfighting lore, the color choice is said to help hide bloodstains, but it may have other advantages. Whereas humans are trichromats—

MARTIN BARRAUD Getty Images (woman in red); SEAN MCCABE (Macknik and Martinez-Conde)

THE WOMAN IN RED

From the iconic scarlet soles on Christian Louboutin shoes to the gowns of starlets at the Oscars, wearing red turns heads. Psychologists Andrew J. Elliot and Daniela Niesta Kayser, both then at the University of Rochester, found that male experimental participants perceived women as more attractive and sexually desirable when wearing red, as compared with seeing the same women in other colors or achromatic hues. Somehow red causes a viewer to favor one candidate over another.

In a different look at the color's allure, Nicolas Guéguen of the University of South Brittany in France asked female confederates to wear red, pink or brown lipstick, or none at all, while sitting at a bar. Men approached women in red lipstick fastest and most often. Heightened contrast between eyes, lips and other facial features may make faces appear more feminine.

BY SUSANA MARTINEZ-CONDE AND STEPHEN L. MACKNIK

Susana Martinez-Conde and Stephen L. Macknik are professors of ophthalmology at SUNY Downstate Medical Center in Brooklyn, N.Y. They serve on *Scientific American Mind*'s board of advisers and have authored *Sleights of Mind,* with Sandra Blakeslee (http://sleightsofmind.com), and the forthcoming *Champions of Illusion,* which will be published by Scientific American/Farrar, Straus and Giroux.

With special contributor Leandro L. Di Stasi, a Talentia/Marie Curie fellow at the University of Granada in Spain. He works in the field of neuroergonomics.

Send suggestions for column topics to **editors@SciAmMind.com** meaning that we have three types of retinal cones sensitive to long (red), medium (green) and short (blue) wavelengths—cattle are dichromats: they possess only two kinds of cones.

Perceptual measurements indicate that cattle can discriminate red from green and blue but not green and blue from each other. Moreover, researchers have found that cattle are more active and aroused in red light than in blue or green light. Another study reported that although fighting bulls may charge all sorts of moving objects, the charges carry greater force when directed against warm colors such as red.

In the 1960s the late Spanish-born neuroscientist José M. R. Delgado, then at Yale University, pitted the lure of the red matador's cape against the power of direct brain stimulation by testing whether electronic brain implants could stop a charging bull in its tracks. With the implants linked to a remote control, Delgado climbed into an arena in Córdoba, Spain, and enraged the bull with his cape. His move was a bold one: if Delgado's idea to directly stimulate the caudate nucleus, an area involved in voluntary motion, failed, he would pay the ultimate price. The bull charged—*¡Olé!*—but Delgado remembered to mash the remote's button in the nick of time, stopping the toro mid-charge. Even if red has the power to lure a bull to attack, little, if anything, can beat direct brain stimulation.

As the examples that follow illustrate, red regularly sways behavior. Charged with social and cultural meanings, it is a powerful enhancer, sending signals that may not really reflect an entity's true nature. **M**

RED BADGE OF COMPETITION

In some species, red coloration signals testosterone-driven dominance. Evolutionary anthropologists Russell A. Hill and Robert A. Barton, both at Durham University in England, thus reasoned that red might confer a competitive edge in humans. They analyzed the outcomes among contestants, based on attire, in four combat sports in the 2004 Summer Olympic Games: boxing, tae kwon do, Greco-Roman wrestling and freestyle wrestling.

Throughout the games, red and blue outfits and protective gear were assigned randomly to the athletes. If color had exerted no influence, there should have been an approximately equal number of wins and losses for the two hues. This was not the case, however. In all four sports, contestants wearing red won more fights than those in blue. The advantage was most pronounced when the participants were well matched. A few possible explanations for this result are that the referees favored red fighters, that crimson-clad combatants felt more powerful or that the color made opponents cower. Whatever the reason, the red athletes had a critical advantage over rivals—even if the edge was illusory. Hill and Barton found similar results in an international soccer tournament, suggesting that the color of sportswear may affect a variety of sporting outcomes.

FALSE ADVERTISING

In the animal kingdom, a flash of crimson can be a warning sign. As the venomous Sonoran coral snake of western North America reveals, the color is often code for poison, keeping predators away. But other creatures can exploit this signal to their advantage. The Sonoran mountain king snake (*shown at left*), for example, is safer prey but is covered in red stripes that may trick other animals into thinking it is toxic. Biologists call this kind of resemblance Batesian mimicry, named after the naturalist, Henry Walter Bates, who first described the adaptation in the mid-19th century.

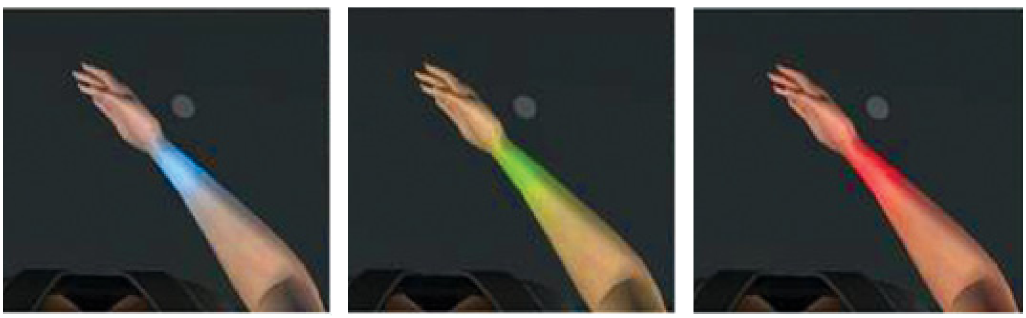
FRANCISCO SECO *AP Photo* (*Cristiano Ronaldo*); DANIEL HEUCLIN *Corbis* (*Sonoran mountain king snakes*)

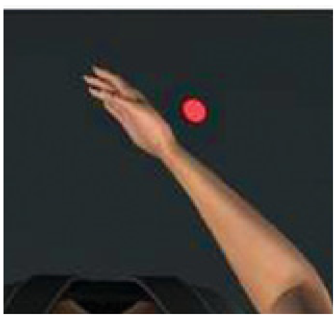
THE MOST VISIBLE FIRE TRUCK

Stop signs, danger warnings, fire extinguishers—people commonly assume that they are colored red because the hue is intrinsically more attention-grabbing. But ruby's reputation may be oversold. When one of us (Macknik) worked as a firefighter at what was then the University of California, Santa Cruz, Fire Department as an undergraduate student, he was initially disappointed to find out that its trucks were painted lime yellow. At the end of his first day on the job, he asked then fire captain Paul Babb why. "Because they're not ripe yet," Babb deadpanned.

In fact, public safety department records show that the probability of a visibility-related accident is higher for a red or red-and-white pumper than for a lime-yellow fire truck. Lime yellow, which falls in the middle of the color spectrum, is easy to see during the day, when we rely on our trichromatic cone vision, and is the most visible wavelength at night, when human vision is dominated by achromatic rods rather than cones. Red may mean fire, but lime yellow is the real eye-catcher.

COLOR OF PAIN





Red may intensify the experience of pain, according to recent research. Neuroscientist Maria Victoria Sanchez-Vives and her colleagues at the University of Barcelona in Spain applied heat to the wrists of experimental subjects experiencing a virtual environment through a head-mounted display.

As the intensity of the heat rose, participants saw virtual arms become increasingly red (*top right*), blue (*top left*) or green (*top center*) and pressed a button whenever the sensation became painful. In an additional experimental condition (*bottom*), a gray dot close to the virtual arm turned red as the temperature increased, but the color of the arm itself remained unaltered. Of all four conditions, subjects experienced pain earliest (that is, at the lowest temperatures) when the virtual arm was red. So much for looking at life through rose-colored glasses!

FURTHER READING

- **Fire Truck Visibility: Red May Not Be the Most Visible Color, Considering the Rate of Accident Involvement with Fire Trucks.** Stephen S. Solomon and James G. King in *Ergonomics in Design,* Vol. 5, No. 2, pages 4–10; April 1997.
- **Sporting Contests: Seeing Red? Putting Sportswear in Context.** Candy Rowe, Julie M. Harris and S. Craig Roberts in *Nature,* Vol. 437, page E10; October 27, 2005.
- **Romantic Red: Red Enhances Men's Attraction to Women.** Andrew J. Elliot and Daniela Niesta in *Journal of Personality and Social Psychology,* Vol. 95, No. 5, pages 1150–1164; November 2008.
- **Does Red Lipstick Really Attract Men? An Evaluation in a Bar.** Nicolas Guéguen in *International Journal of Psychological Studies,* Vol. 4, No. 2, pages 206–209; June 2012.

FROM "WHAT COLOR IS MY ARM? CHANGES IN SKIN COLOR OF AN EMBODIED VIRTUAL ARM MODULATES PAIN THRESHOLD," BY MATTEO MARTINI ET AL., IN *FRONTIERS IN HUMAN NEUROSCIENCE,* VOL. 7; JULY 31, 2013 (*arm images*); HENRY DILTZ *Corbis* (*fire truck*)

HUB OF SENTIENCE

A Brain Structure Looking for a Function

Could a thin, enigmatic layer of nerve cells be a key component of the networks generating conscious experience?

Point to any one organ in the body, and doctors can tell you something about what it does and what happens if that organ is injured by accident or disease or is removed by surgery—whether it be the pituitary gland, the kidney or the inner ear. Yet like the blank spots on maps of Central Africa from the mid-19th century, there are structures whose functions remain unknown despite whole-brain imaging, electroencephalographic recordings that monitor the brain's cacophony of electrical signals and other advanced tools of the 21st century.

Consider the claustrum. It is a thin, irregular sheet of cells, tucked below the neocortex, the gray matter that allows us to see, hear, reason, think and remember. It is surrounded on all sides by white matter—the tracts, or wire bundles, that interconnect cortical regions with one another and with other brain regions. The claustra—for there are two of them, one on the left side of the brain and one on the right—lie below the general region of the insular cortex, underneath the temples, just above the ears. They assume a long, thin wisp of a shape that is easily overlooked when inspecting the topography of a brain image.

Advanced brain-imaging techniques that look at the white matter fibers coursing to and from the claustrum reveal that it is a neural Grand Central Station. Almost every region of the cortex sends fibers to the claustrum. These connections are reciprocated by other fibers that extend back from the claustrum to the originating cortical region. Neuroanatomical studies in mice and rats reveal a unique asymmetry—each claustrum receives input from both cortical hemispheres but only projects back to the overlying cortex on the same side. Whether or not this is true in people is not known. Curiouser and curiouser, as Alice would have said.

Unlike most other parts of the brain,

BY CHRISTOF KOCH

Christof Koch is chief scientific officer at the Allen Institute for Brain Science in Seattle. He serves on *Scientific American Mind's* board of advisers.

Send suggestions for column topics to **editors@SciAmMind.com**

JON HAN (*illustration*); SEAN MCCABE (*Koch*) there are no reliable case studies of patients with selective destruction of one or both claustra from stroke, viral infection or other calamity. Lesioning the structure in laboratory animals is challenging given its thin and elongated nature. For the same reason, brain imaging has not been very useful: the smallest spatial features distinguishable through positron-emission tomography or functional MRI, two of the most widely used imaging techniques, are two to three millimeters across, bigger than the claustrum's width. And because it is embedded within white matter and sandwiched between two very active neuronal tissues—below the neocortex and above the putamen, part of a larger region, the basal ganglia, lodged deep within the brain—it is problematic to unambiguously pinpoint changes in blood flow to the claustrum and not to these nearby, large structures.

FRANCIS CRICK AND I HYPOTHESIZED THAT THIS SUPERHUB OF NEURONAL ACTIVITY **COULD BE PIVOTAL FOR CONSCIOUSNESS.**

Enter the Dragon

In biology, a reliable guide to understanding function is to study structure. Francis Crick and James Watson proved this idea spectacularly in 1953. They inferred the key function of DNA, the molecule of heredity—that is to say, storing and copying genetic information—from its double-helical chemical structure. Half a century later Crick, by then biology's most respected sage, tried his hand at the same game, linking a structure—the claustrum—to a function—the emergence of integrated, conscious experience.

Whereas scholars of consciousness disagree about many aspects of this most mysterious phenomenon, virtually all agree that one of the defining properties of any subjective experience is that it is unified. No experience can be reduced to independent components. Every experience is irreducible. When I look at my wife's face, I do not see two eyes in a black-and-white picture with a disembodied layer of blue superimposed on top. No, I perceive her blue eyes as one integral and seamless whole. Nor do I experience my Bernese mountain dog doing funny things with her snout while a loud noise fills the room; no, I hear her bark. The experience of seeing the word "honeymoon" is not reducible to the experience of seeing "honey" on the left and "moon" on the right.

We know that different groups of neurons become active in response to such commonly encountered features as colors and motion, faces and dogs, words, sounds, and so on. These cells are dispersed among the 16 billion neurons making up the cerebral cortex. Together the active and inactive cells give rise to a conscious experience. Furthermore, we know from introspection that what we are conscious of is in constant flux.

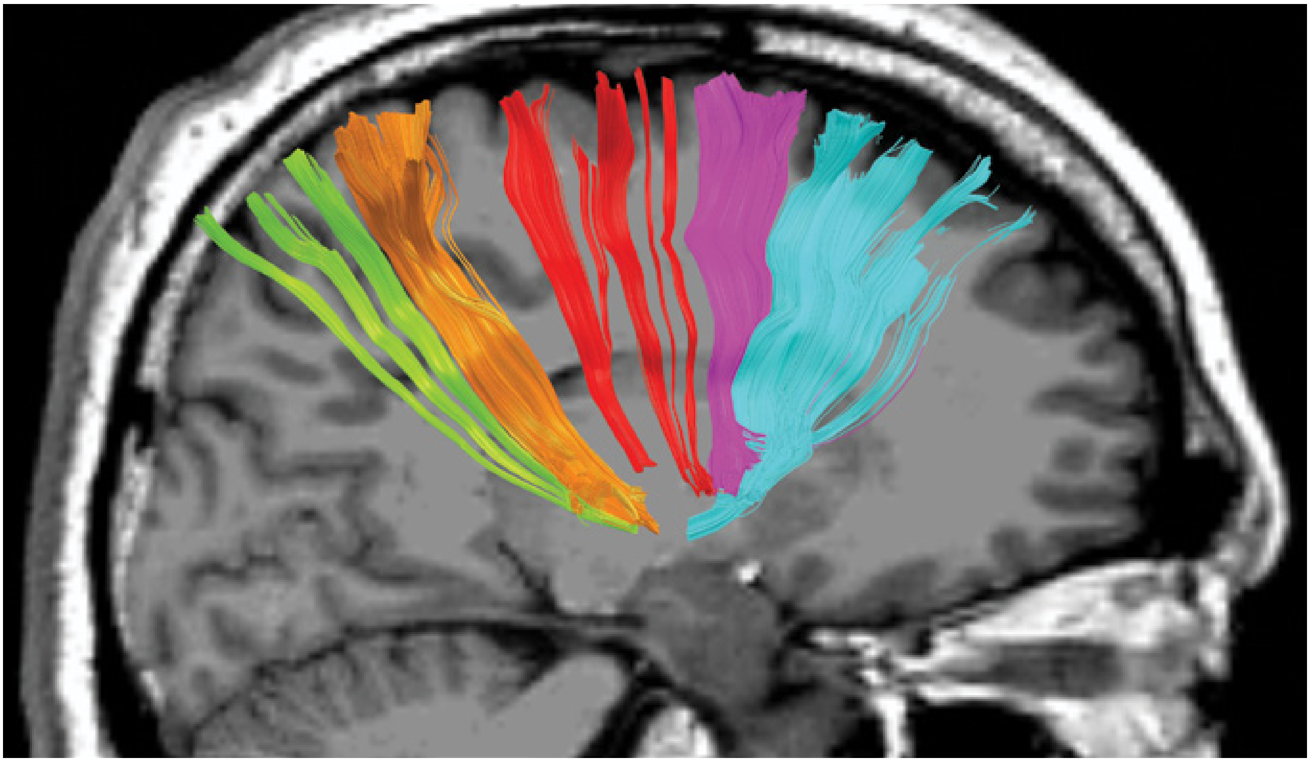
Distracted by the sight of a passing motorboat on the lake outside my house, I am about to turn back to writing my article when I suddenly recall that I promised to pick up dog food, and then my attention shifts without warning to Richard Wagner's "Liebestod" playing on the radio. Each of these sights, sounds, memories or thoughts requires that the underlying electrical and chemical activity of a privileged set of neurons is rapidly bound to give rise to an integrated conscious experience that lasts but a fleeting moment until the next neuronal assembly comes into being and a new experience supersedes the old one.

Looking at the far-flung two-way connections between the claustrum and the cortex, Crick and I—for at that time in 2004, I was working closely with him and had been for 16 years—hypothesized that this superhub of neuronal activity could be pivotal for consciousness. Because every region of cortex projected to its associated claustral target area, and this neural communications hub reciprocated the connection, the claustrum could serve as an integrator for crisscrossing electrical signals, provided that all of this information could be freely admixed within the structure. We endlessly discussed various neuroanatomical and biophysical means for the claustrum to achieve this integration and wrote a manuscript.

Francis knew that he only had a limited amount of time left; he had end-stage colon cancer. He called me on the way to the hospital, calmly telling me not to worry about the manuscript following our last brainstorming session because he was going to make corrections to it (which he did, dictating them to his secretary from the clinic). Two days later, on his deathbed, Francis hallucinated a debate with me about the role of the claustrum's connection to consciousness, a scientist to the very end. The paper was published a year later in the world's oldest scientific journal, the *Philosophical Transactions of the Royal Society*.

Enter the Electrodes

In the intervening years, a handful of studies further delineated the molecular neuroanatomy of the claustrum in rodents and a crude map of its connections in people. One investigation focused on the role of the claustrum in integrating visual and auditory stimuli. Using microelectrodes that recorded the electrical activity in awake monkeys, the investigators confirmed that part of the claustrum



A possible nexus of consciousness, the claustrum reveals itself through high-definition fiber tractography as a locus at which connections arrive from—and extend outward to—distinct regions of the cerebral cortex.

tended to respond more to visual stimuli, whereas one of its nearby regions was sensitive to tones. But no individual neurons responded to both visual and auditory events, arguing against a multisensory role for the claustrum, thereby leaving it bereft of any obvious function.

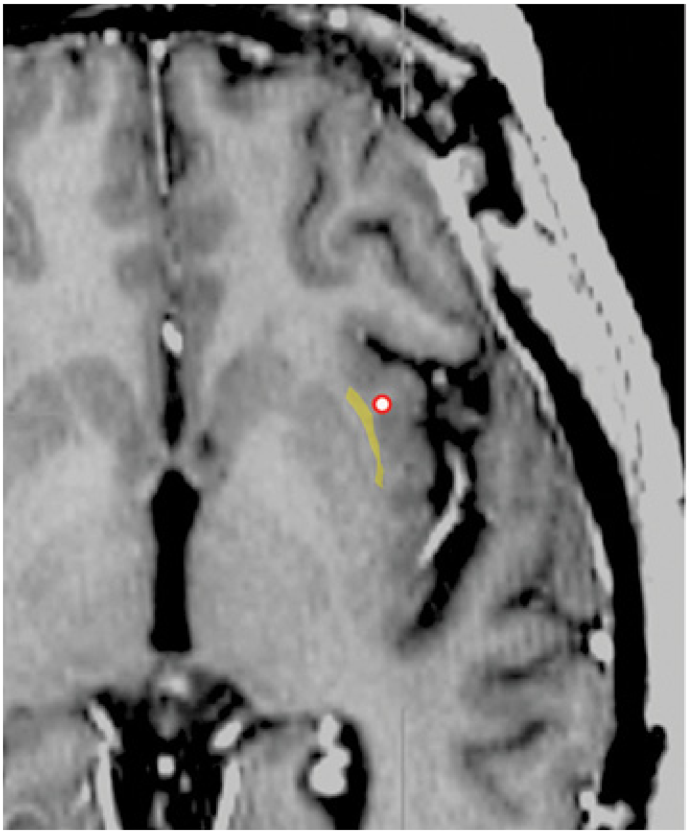
This seeming impasse may have changed with a single dramatic case report. A 54-year-old woman who had uncontrollable epileptic seizures had electrodes implanted deep within her brain to help pinpoint the exact origin of her seizures. During this procedure, electrodes can triangulate the focal area where the seizure originates so that it can be surgically removed. They can also inject electric current to help map the brain, identifying areas responsible for important functions such as speech or movement and thus sparing them during the surgery.

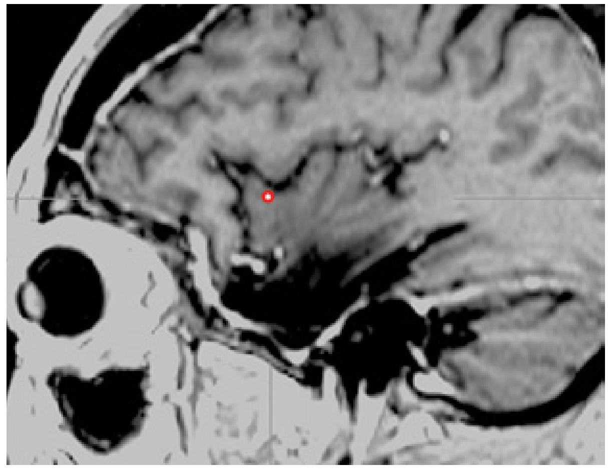
Led by Mohamad Z. Koubeissi, an associate professor in the department of neurology at George Washington University, the clinical team made a remarkable observation: electrically stimulating a single site with a fairly large current abruptly impaired consciousness in 10 out of 10 trials—the patient stared blankly ahead, became unresponsive to commands and stopped reading. As soon as the stimulation stopped, consciousness returned, without the patient recalling any events during the period when she was out. Note that she did not become unconscious in the usual sense, because she could still continue to carry out simple behaviors for a few seconds if these were initiated before the stimulation started—behaviors such as making repetitive tongue or hand movements or repeating a word. Koubeissi was careful to monitor electrical activity throughout her brain to confirm that episodes of loss of consciousness did not accompany a seizure.

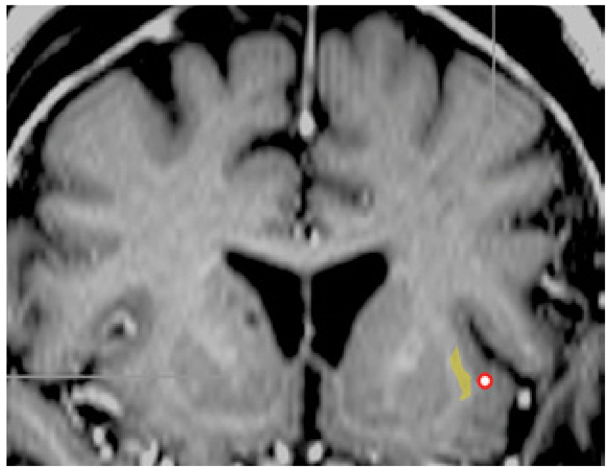
Two aspects of this patient's case had never been seen before. First, no abrupt and specific cessation and resumption of consciousness have previously been reported, despite decades of electrically stimulating the forebrain of awake patients in the operating room. Depending on the location of the stimulating

ELECTRICAL STIMULATION OF A SINGLE SITE IN THE BRAIN IMPAIRED CONSCIOUSNESS IN **EVERY ONE OF 10 EXPERIMENTAL TRIALS.**

COURTESY OF JUAN C. FERNANDEZ-MIRANDA *University of Pittsburgh*







A switch that toggles consciousness off and on consists of a simple electrode (*red circle*) near the claustrum (*yellow*). Stimulation by the electrode at that location—shown from three perspectives—abruptly curtailed all conscious activity until the current flow stopped.

FROM "ELECTRICAL STIMULATION OF A SMALL BRAIN AREA REVERSIBLY DISRUPTS CONSCIOUSNESS," BY MOHAMAD Z. KOUBEISSI ET AL., IN *EPILEPSY & BEHAVIOR,* VOL. 37; AUGUST 2014

electrode, patients usually do not feel anything in particular. Less frequently, a patient may report flashes of light, smells or some difficult-to-verbalize body feelings, or perhaps even a specific memory from long ago that the electric current evokes. Or the patient will twitch a finger or a muscle. But this case was different. Here consciousness as a whole appeared to be turned off and then on again. Second, it happened only at a single place, in the white matter close to the claustrum and the cortex. Because electrical stimulation of the nearby insula is not known to elicit a loss of consciousness, the researchers implicated the claustrum.

It is difficult to be confident of the actual causal mechanisms—the stimulation may have triggered electrical discharges from neurons' wirelike extensions to exert effects at another site. Unfortunately, this tantalizing case report cannot easily be followed up with more experiments, because the patient's electrodes were subsequently removed.

We do not have the luxury of waiting for an analogous finding, perhaps as long as a century hence, so it is important to devise experiments to confirm the existence and properties of any claustrum on/off switch. The most promising idea would take advantage of proteins specifically expressed in cells in the claustrum but not in other brain structures. Knowledge of these cells' molecular zip code can then be exploited by tools of molecular biology to quickly and transiently turn the electrical activity of neurons in the claustrum off and on with beams of colored light and to observe the effects on the behavior of lab mice.

If the claustrum truly plays a critical role in generating conscious experiences, we will find out and take another small step toward the ultimate goal of identifying the footprints of consciousness in highly excitable matter. *Per claustra ad astra!* **M**

FURTHER READING

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The FUTURE of the BRAIN

More than 2,300 years ago Aristotle famously wrote that we are more than the sum of our parts. This nugget of wisdom still resonates today, for at least one simple reason: connections. In the past two decades technology has transformed our understanding of what it means to be truly connected. Easy access to centuries of knowledge, and to like-minded thinkers worldwide, allows new ideas to coalesce at a startling speed.

In this special issue of *Scientific American Mind,* we take stock of key advances that are altering the way we think about connectivity and the human brain. Through technology, inventions that until recently were considered pure fantasy—a direct link between brains, machines that can reconstruct dreams, tiny solar panels embedded in neurons—are now facts of life. Welcome to the future.

At a cellular level, technology is revealing how a person's neurons update themselves to generate a living library of experience. This plasticity—fodder for the marketing campaigns of countless self-help guides—makes us adaptive, creative and intelligent. Yet its mechanisms have long bedeviled scientists. In the first part of the report, "The Neural Code," we explore how emerging techniques are letting us hack the brain, to lay bare its secrets and extend our influence past the boundaries of flesh and bone.

A single brain is a computing marvel, but it pales in comparison to the powers of the networked mind. Social ties also permit us to surpass limitations, whether it be through an act as humble as asking a friend for advice or as ambitious as banding together to build a better smartphone. Tapping into human connections has never been easier, and in our report's second section, "The Social Web," we examine how interpersonal relationships manifest online. Love and hate persist—but with a digital twist.

To make the most of our networked noggins, we still need to address a critical issue: the toll of mental illness, a leading cause of disability worldwide. Here, too, our collective brain trust may at last be making headway. The final chapter, "The Healing Touch," explores advances in modifying the brain, both to tweak problematic circuitry and to answer urgent questions about what causes dysfunction. The approaches described in this section are helping psychiatry become tech-savvy.

Technology is reshaping the brain sciences as well as brains themselves. By connecting ourselves to computers in numerous ingenious ways, we are pushing the limits of what we can each accomplish. Aristotle would be proud—or at least astounded.

—*The Editors*

Illustration by **VAULT 49**

CYBORG *CONFIDENTIAL*

Hooking the brain up to a computer can do more than let the severely disabled move artificial limbs. It is also revealing the secrets of how we learn

By Sandra Upson

At 9:15 in the morning two or three times a week, Jan Scheuermann maneuvers her electric wheelchair into a research laboratory at the University of Pittsburgh, where she plugs her head into a highly sophisticated piece of equipment. Two ports in her scalp connect to a prosthetic limb, a sleek, black anthropomorphic arm that extends from a metal scaffold in the lab. She is one of a dozen or so volunteers worldwide who have received brain implants as part of multiyear experiments on how to manipulate objects with their thoughts alone. More than any other user of brain-controlled prostheses, Scheuermann has learned to wield the arm with exquisite dexterity, articulating individual fingers to shake hands and rearrange objects at a wide range of speeds. "Every day I go to work, I think, this is the coolest thing," she says.

Scheuermann began losing control of her muscles in 1996. As her genetic disorder—spinocerebellar degeneration—took its toll, she gave up her successful business as a planner of murder-mystery-themed events. By 2002

Illustration by **VAULT 49**

her disease had confined her to a wheelchair, which she now operates by flexing her chin up and down. She retains control of the muscles only in her head and neck. "The signals are not getting from my brain to my nerves," she explains. "My brain is saying, 'Lift up!' to my arm, and my arm is saying, 'I caaaan't heeeear you.'"

Yet technology now exists to extract those brain commands and shuttle them directly to a robotic arm, bypassing the spinal cord and limbs. Inside Scheuermann's brain are two grids of electrodes roughly the size of a pinhead that were surgically implanted in her motor cortex, a band of tissue on the surface of the brain that controls movement. The electrodes detect the rate at which about 150 of her neurons fire. Thick cables plugged into her scalp relay their electrical activity to a lab computer.

As she thinks about moving the arm, she produces patterns of electrical oscillations that software on the computer can interpret and translate into digital commands to position the robotic limb. Maneuvering the arm and hand, she can clasp a bar of chocolate or a piece of string cheese before bringing the food to her mouth. When she succeeds in performing a task with a new level of fluency, the researchers in the room break into applause. "Any time I did something faster we'd all say, "Ah, a new world record!'" she says.

Scheuermann calls herself a "guinea pig extraordinaire." Her story—and that of other paraplegics fitted with brain-activated prostheses—often gets featured on television news shows or in the science pages of popular magazines. Once perfected, these fledgling technologies hold obvious appeal for letting the wheelchair-bound reach for an object or even get up and walk.

Less attention has gone to another critical contribution made by Scheuermann and others fitted with paraphernalia that jack into the brain—and by the primates and rodents that also participate in these experiments. This select group has given neuroscientists an unprecedented view of how the brain proceeds from thought to action and how it develops a new skill. Numerous experiments with this group are now documenting how brain circuits rewire as a neophyte evolves from bumbling ineptitude to fluid proficiency. Implants that eavesdrop on dozens of neurons provide scientists a window through which to watch how practice breeds mastery at the level of an individual brain cell—not only in a paraplegic but in anyone honing a new ability.

FAST FACTS
PROSTHETIC LEARNING

1. Brain-computer interfaces are being developed to assist people with physical handicaps. Yet scientists are also using these tools to gain insight into the cellular mechanisms of learning.
2. Recordings of neural activity reveal how neurons adjust their firing patterns as an individual becomes more proficient at a task.
3. Neurons rely on different techniques when they attempt a task for the first time, correct mistakes to improve and ultimately lock in memories.

In 2012 Jan Scheuermann used her brain implant to maneuver a robotic arm toward a bar of chocolate, grasp it in its fingers, and move it to her mouth to take a bite.

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Forming Machine Memories

When neuroscientists first set out to develop brain-controlled prostheses, they assumed they would simply record neural activity passively, as if taping a speech at a conference. The transcript produced by the monitored neurons would then be translated readily into digital commands to manipulate a prosthetic arm or leg. "Early on there was this thought that you could really decode the mind," says neuroscientist Karunesh Ganguly of the University of California, San Francisco.

Yet the brain is not static. This extraordinarily complex organ evolved to let its owner react swiftly to changing conditions related to food, mates and predators. The electrical activity whirring inside an animal's head morphs constantly to integrate new information as the external milieu shifts.

Ganguly's postdoctoral adviser, neuroscientist Jose M. Carmena of the University of California, Berkeley, wondered whether the brain might adapt to a prosthetic device as well. That an implant could induce immediate changes in brain activity—what scientists call neuroplasticity—was apparent even in 1969, when Eberhard Fetz, a young neuroscientist at the University of Washington, reported on an electrode placed in a monkey's brain to record a single neuron. Fetz decided to reward the animal with a banana-flavored pellet every time that neuron revved up. To his surprise, the creature quickly learned how to earn itself more bites of fake banana. This revelation—that a monkey could be trained to control the firing rate of an arbitrary neuron in its brain—is what Stanford University neuroscientist Krishna Shenoy calls the "Nobel Prize moment" in the field of brain-computer interfaces.

Of course, neurons adjust their behavior any time a person learns, whether it is a student becoming fluent in French or a skater finally landing a triple Axel. Yet by training an animal to control a particular cell or set of cells, scientists can observe the process unfolding in those exact neurons. Specifically, researchers monitor the bespoke firing pattern, or tuning, of each neuron under surveillance in an implantee's motor cortex.

She would tell the experimenters jokes or regale them with stories of her family while she directed the prosthetic limb to stack cups or move blocks.

A neuron's tuning contributes a bread crumb of information on how to execute a movement. One neuron might fire lethargically to command a movement upward, for example. That same cell firing at its maximum rate might signal a leftward tilt. This pattern of activity is called a neuron's preferred direction. Engineers developed software that aggregates all the preferred directions of the recorded neurons firing at a given moment to produce an individual's intended bearing. Later, when someone imagines a movement, the software knows which way to move the robotic limb.

Scientists were beginning to discover, however, that neurons can adjust their tuning in response to the software. In a 2009 study Carmena and Ganguly detailed two key ways that neurons begin to learn. Two monkeys spent several days practicing with a robotic arm. As their dexterity improved, their neurons changed their preferred direction (to point down rather than to the right, for example) and broadened the range of firing rates they were capable of emitting. These tuning adjustments gave the neurons the ability to issue more precise commands when they dispatched their missives.

The neuroscientists then pushed their experiments a step further, testing just how far neuroplasticity could be extended. They scrambled the computer software's control scheme so that the arm now reacted differently to the same inputs of neural data—cells that previously swung the arm to the left now might send it soaring upward. The monkeys had no trouble learning the new rules, and their neurons even reacted by adopting a new firing scheme. In fact, they could switch easily between these firing schemes to control the arm in either mode. "The brain can form something that looks like a natural motor memory for a disembodied device," Carmena says. "To me, that is pretty remarkable."

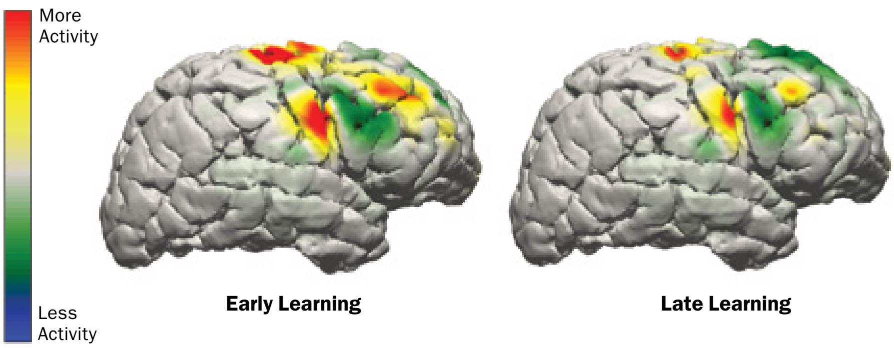
Back in the Pittsburgh lab, Scheuermann, too, has helped shed light on neuroplasticity. She discovered that she performed better when she was relaxed or slightly distracted, so she would tell the experimenters jokes or regale them with stories of her family while she directed the prosthetic arm to stack cups or move blocks. Biomedical engineer Jennifer Collinger of Pittsburgh and her colleagues, in their first major paper on Scheuermann's work with the robotic arm, published in 2013, documented how the neurons in her motor cortex coordinated themselves to better reach the target. "Because of the feedback she was getting about her errors, her neurons appeared to be changing their tuning," Collinger says.

Learning from Mistakes

As Scheuermann observed the arm and the ways in which it missed its mark, she made mental adjustments. Somehow her brain could identify the specific neurons that contributed to her errors. Correcting mistakes in perception or action—the neural equivalent of software bug fixes—is one of the reasons the brain needs to be so readily changeable. Learning itself is nothing more than repeated error correction. Here, too, the brain-computer interface can help.

In work published in 2012 neuroscientist Steven M. Chase of Carnegie Mellon University and his colleagues implanted electrodes next to neurons in the motor cortex of two monkeys. They trained them to use the recorded neurons to control a cursor on a computer screen. Software identified the preferred direction of each recorded cell, as is typical. This time, however, the neuroscientists forced the monkeys to make small mistakes.

They split each monkey's controlling neurons into two groups. The scientists then tweaked the software so that when



A person can learn to control a computer cursor with a neuron or two, but the rest of the brain also contributes. In one study, people with implanted electrodes initially recruited neurons in many regions to try to move a cursor (*far left*). On mastery (*near left*), areas involved in learning were less active, which suggests that subjects' control had grown automatic.

JEREMIAH WANDER *University of Washington*

THE AUTHOR

SANDRA UPSON is managing editor of *Scientific American Mind.*

one group of neurons fired, the directions they moved the cursor were rotated (say, 30 or 60 degrees). The remaining neurons were left alone. Now when the monkey tried to reach a target on the screen, the cursor came up short. Think of pushing a shopping cart with a bum wheel that steers to the right when you want to go straight ahead. To compensate, you push the cart to the left to cancel the rightward bias.

The monkeys' neurons performed a similar realignment when they fired. The animals oversteered by recruiting neurons that pointed past the target. In a crude overcorrection, they also dampened all the neurons that earlier had fired to point directly at the target, including the cells that had not been digitally rotated. In addition, a small number of neurons changed their tuning to point in a different direction, a more permanent shift akin to remodeling the wheel.

In follow-up work, Chase and his colleagues have found that when the monkeys spend weeks practicing with rotated neurons, their brains more aggressively pursue the latter adaptation. Chase suggests that this might occur because permanent retuning simply takes longer. "It requires the network to restructure," he says, whereas a technique such as oversteering uses neurons' existing capabilities and can happen immediately.

Chase's work provides insight into the changes in tuning that solidify motor learning. The new firing patterns become locked into place through alterations in the connection points between neurons, called synapses. Over the course of several days, new synapses grow or old ones weaken, a process that brings about microscopic but lasting shifts to the brain's networks. These subtle tweaks represent the physical basis of a new skill at the level of individual cells and molecules.

Opening a Window

Learning takes place in stages, during which a new task becomes gradually integrated with existing memories. Sleep, in fact, may be crucial in the formation of memories. It has long been noted that people perform better and faster on a wide range of tasks after slumber—whether they are solving differential equations or playing Bach études. Yet what happens during sleep has remained largely guesswork.

Brain-computer interfaces provide a means to follow what happens as sleep helps to solidify recall. In one experiment published in July, Ganguly and his colleagues trained rats to use a brain implant in their motor cortex to move a mechanical tube that dispensed drops of water.

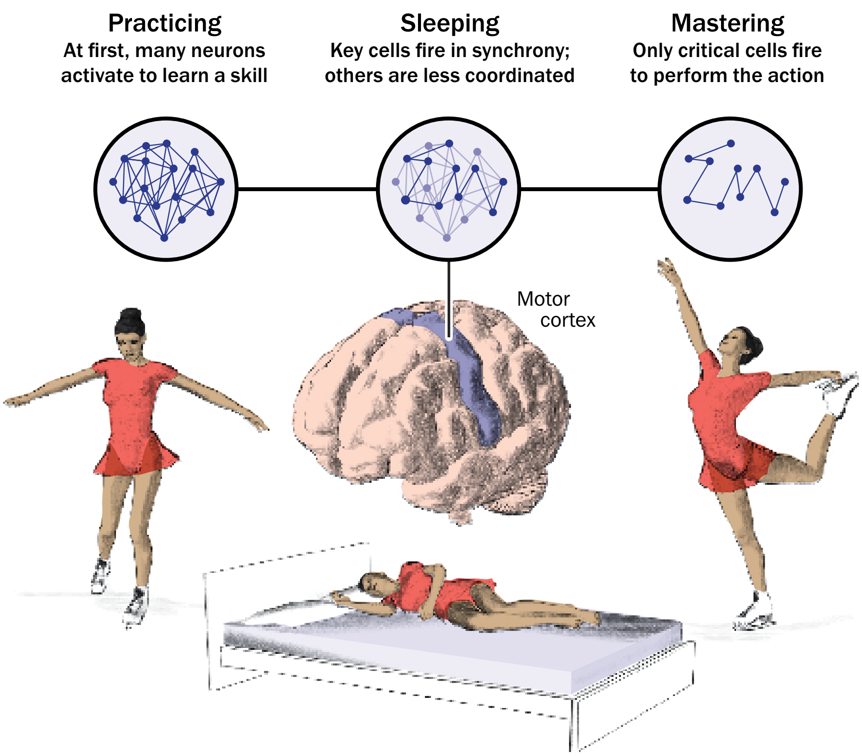
Many of the animals first discovered that they could control the tube after they twitched and saw it move. Soon the twitches died down as most of the rodents figured out that they could activate their motor neurons and trigger a drink without moving a hair. To do so, the animals had to perform an impressive feat of neuronal detective work. The scientists had configured the neuron-reading software to make the tube harder to move whenever one subset of cells fired. To earn a drop of water, the rodents had to sort out which neurons helped them to get a sip and which ones worked against them.

After the rats fell asleep at the end of a day of practice, their implants continued recording from neurons. When the rodents that had aced the task reached deep sleep—characterized by extremely slow, synchronized waves of electrical activity—the neurons that controlled the mechanical tube fired in lockstep. If the rats had performed poorly, these same neurons were slightly out of sync.

The neural processing taking place during the animals' repose appeared to be reinforcing the firing abilities of the mission-critical neurons. Moreover, the longer the

How a Motor Skill Takes Shape

Electrodes implanted in the motor cortex (*purple*) of humans, monkeys and rodents are revealing the ways the brain changes as it learns a new skill. At first, it rallies many neurons. With practice and sleep, it winnows down to a core set of cells. Although this process has only been observed in several dozen neurons at a time, it is likely to be indicative of learning in general.



TAMI TOLPA

rodents spent in deep sleep, the more their performance subsequently improved.

Another study, published in June, also explored how the brain winnows down the neurons it needs to the most critical players during learning. Carmena and his colleagues developed a new technique that allows them to visually survey neurons rather than recording them, as with implanted electrodes. The researchers worked with genetically altered mice whose neurons glowed green when they fired. The scientists installed a glass plate into the rodents' skull through which they could observe neural activity using a microscope. "You're watching live as these cells flash on and off," explains neuroscientist Daniel Feldman, one of the co-authors of the paper.

The researchers could assign any neurons in their field of view to controlling some aspect of the outside environment—in this case, the pitch of an auditory tone. The experimenters played a tone, and the animals could learn to activate their neurons to make it rise or fall. In one part of this study, the scientists picked two small groups of neurons. When the first group fired, the pitch rose. When the second set came on, it dropped. The rats were rewarded with a drop of water whenever they managed to hit a high-pitch target. "It couldn't be more abstract for the rat. It has no idea what you want it to do," Carmena says. "Getting a rat to increase the firing rate in one ensemble and decrease the other—that is an extremely abstract thing to learn."

As each rat practiced modulating the pitch, the neuroscientists watched through the glass window in the animal's head. Early in training, neighboring neurons glowed alongside the ones that controlled pitch. Yet within an hour the firing pattern became more precise, and these adjacent cells had gone dim.

The rodents seemed to be picking the individual cells that really mattered to form a concise and well-organized memory of their new skill. Out of the millions of neurons in their brains, the rats could identify the couple of cells that stood between them and their coveted drink.

Out of the millions of neurons in their brains, the rats could identify the couple of cells that stood between them and their coveted drink.

Your Pliant Brain

Carmena and Feldman continued their experiments by adding yet another twist. They and their colleagues not only granted rats control over neurons in the motor cortex, as most studies on brain-computer interfaces do. They also grafted windows into a chunk of the somatosensory cortex, an area nestled behind the motor cortex that typically handles sensory information. The rats aced the same pitch-control test with cells in this region, too.

"Some voluntary process is reaching up into the sensory part of the brain and making it spike," Feldman says. Impulses specific to movement, it seems, may not be all that vital to prosthetic control. Carmena's team is now investigating neurons in other parts of the brain and finding that rodents can learn to control them with ease.

These discoveries imply that the brain is perhaps more pliable than anyone may have realized. They raise the question of whether any neuron, with the right kind of feedback, might be trained to do an animal's bidding. "For brain-machine interfaces, you just want cells you can volitionally control," Fetz says. "And I'm thinking they're all over the place, not just in motor areas. You could open up a lot of territory for gaining control."

That would be good news for stroke patients or others who have lost mobility because of a damaged motor cortex. Brain areas that were spared when blood flow was interrupted might be able to pick up the slack.

Fully implantable devices that restore movement to paralyzed patients probably are still a couple of decades away. Scheuermann, for one, is well aware that she is unlikely to ever get her own personal robotic limb. Her interest in the project stems more from the altruistic streak that tends to emerge as a natural consequence of illness or disability. "It's given me such a sense of purpose," she says. Although her goal is to eventually help other people with disabilities, she has also come to appreciate the contribution her brain can make in revealing the inner workings of the mind. She even nicknamed the ports in her scalp Lewis and Clark, for their vital role in exploring the brain's cryptic landscape. M

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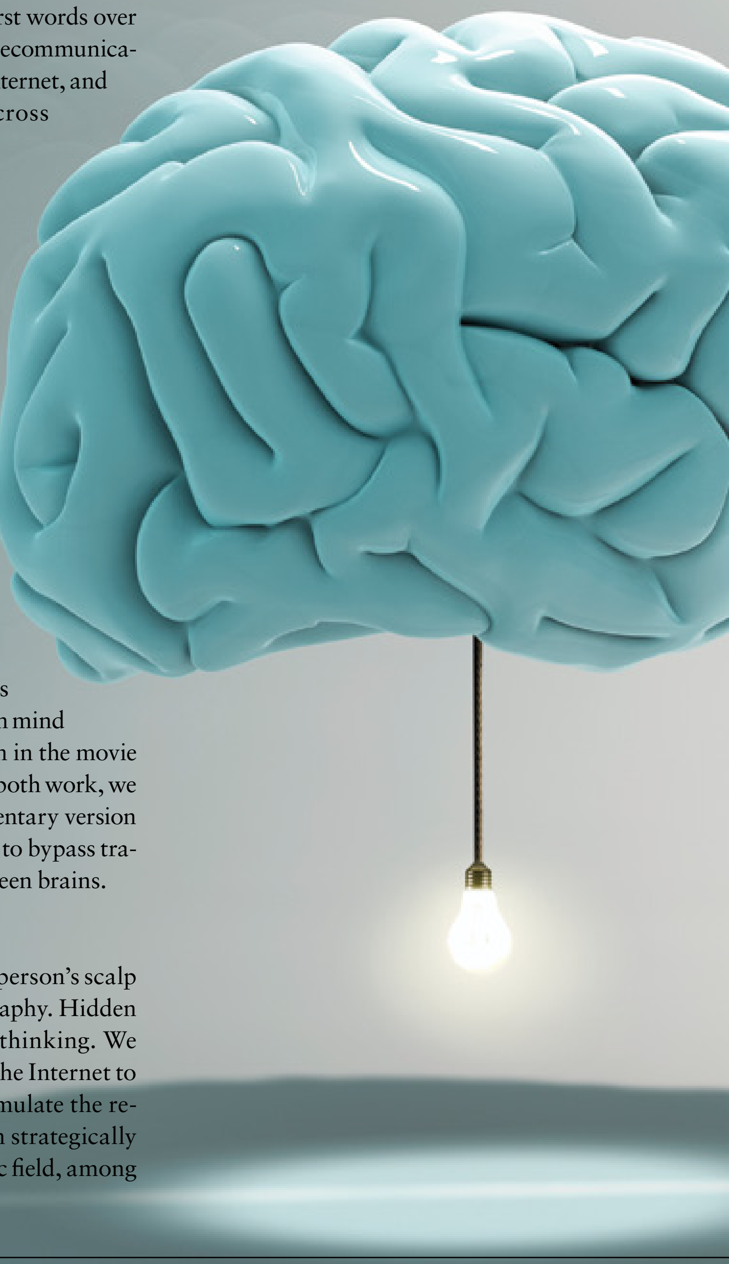
WHEN TWO BRAINS

"Mr. Watson, come here!" Alexander Graham Bell uttered these first words over a telephone 138 years ago. With that statement he ushered in the telecommunications revolution that would ultimately bring us mobile phones, the Internet, and near-instantaneous exchanges of speech, text and video across continents.



Yet speech can be limiting. Some abstract concepts and emotions can be difficult to convey with words. And certain disabilities rob people of their full communicative powers even as their minds remain otherwise intact.

Neural engineers have spent several decades developing ways to overcome such impairments. Technologies known as brain-computer interfaces (BCIs) are now beginning to allow paralyzed individuals to control, say, a computer cursor or a prosthetic limb with their brain signals. BCIs rely on data-processing techniques to extract a person's intention to move and then relay that information to the device he or she wishes to control.

In 2010 one of us (Rao) had a realization: perhaps we could use this same principle to beam thoughts from one human brain to another. Imagine if a teacher could convey a mathematical proof directly to your brain, nonverbally. Or perhaps a medical student could learn a complex surgical skill straight from a mentor's mind. Such ideas have been a staple of science fiction, from the Vulcan mind meld of *Star Trek* to the control of an avatar by a paraplegic human in the movie *Avatar*. In conversations at the University of Washington, where we both work, we realized that we had all the equipment we needed to build a rudimentary version of this technology. Along with other scientists, we are now learning to bypass traditional modes of communication and swap thoughts directly between brains.

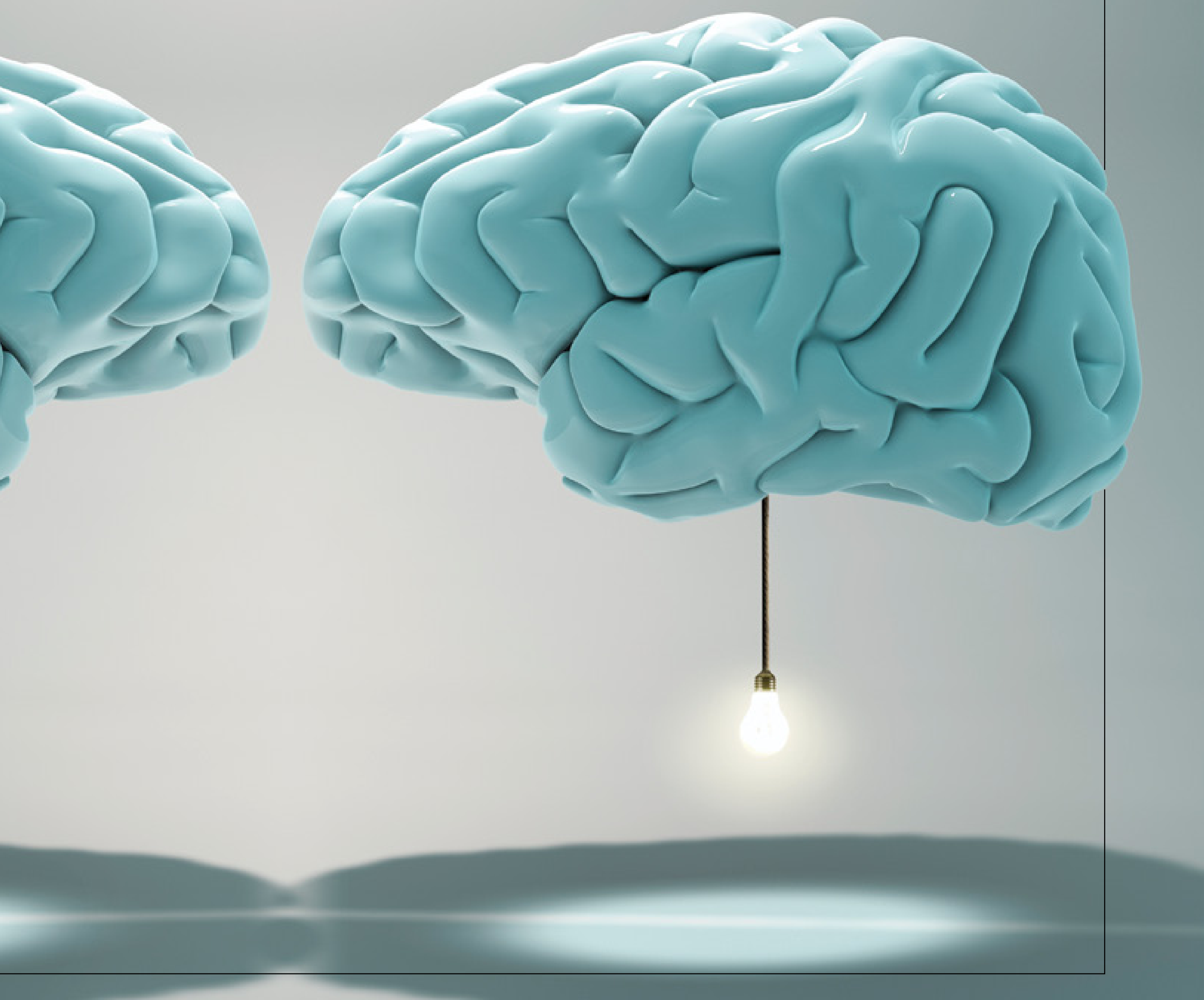
Mind Melds Made Real

The gist of our strategy was to use electrodes arranged on one person's scalp to pick up brain waves, a technique known as electroencephalography. Hidden in that neural hubbub are signals that indicate what a person is thinking. We would focus on extracting one such pattern and then send it over the Internet to a second person. The signal would dictate how to electrically stimulate the recipient's brain. Because neurons communicate electrically, we can strategically influence their messaging by applying electric current or a magnetic field, among

CONNECT

The dawn of human brain-to-brain communication has arrived

By Rajesh P. N. Rao and Andrea Stocco



FAST FACTS
CONNECTED BRAINS

1. Two humans have transmitted thoughts directly between their brains in a recent experiment.
2. Scientists used electroencephalography to decode the neural chatter in a sender's brain and transcranial magnetic stimulation to induce neurons to fire in a recipient's brain.
3. Direct brain-to-brain communication may one day offer a fundamentally different way for people to share and transfer knowledge.

other tricks. In short, we would use one person's brain data to produce a specific pattern of neural activity in another individual.

By the time we finally tried out our design, two other teams of neuroscientists had also transmitted signals directly between brains, though not between two humans. The experiments so far, including ours, have been simple proofs of concept: one participant is designated the sender, and the other subject is the receiver. Ultimately we want to send and receive information in both directions, but we believe the challenges of that next step will be surmountable.

Miguel Nicolelis of Duke University and his team were the first to demonstrate brain-to-brain messaging. In early 2013 they published an experiment in which simple communiqués were transmitted between two rats on different continents. Later that year another experiment was published that involved humans as the senders. In it, six people wearing an EEG headset were each paired with an anesthetized rat. Seung-Schik Yoo of Harvard Medical School and his collaborators made use of an emerging technique that delivers highly focused ultrasonic energy through the skull to specific regions of the brain. When a participant decided to move the rat's tail, that person's corresponding brain activity triggered an ultrasonic pulse that entered the rodent's brain. The 350-kilohertz burst of acoustic pressure was aimed at the rat's motor cortex, which controls movement. About two seconds later the rodent's tail lifted and then fell.

Firing Cannons with Neurons

Similar to Yoo's effort, our experiment also used EEG to identify the control signal. The Rao laboratory has many years of experience extracting intentions from EEG signals, so it was a natural place to start. Once a computer decodes a neural message, the main question becomes how to deliver it. Somewhat serendipitously, one of us (Stocco) and our colleague Chantel Prat were investigating transcranial magnetic stimulation (TMS), a technology approved by the Food and Drug Administration for the treatment of major depression. This method relies on pulses of a magnetic field to induce neurons in a specific area of the recipient's brain to fire.

To deliver the pulses, you place an insulated metal coil next to a person's head. When electricity discharges into the coil, a magnetic field forms around the neurons in the area near the coil. When the electricity stops running, the magnetic field disappears. The sudden rise and fall of the magnetic field induces a tiny electric current in the neurons that had been engulfed by that field, making them more likely to fire. When they do, a chain of connected neurons also activates.

Depending on how you position the coil and configure the magnetic field, you can also induce involuntary movements. We realized we could use this generally unwanted aspect of the technology to generate crude motions in a recipient. In our setup, Stocco would sit with a TMS coil over his left motor cortex, the brain area that controls the movement of his right hand. After some fiddling with parameters, we found the arrangement needed to stimulate the neurons that control Stocco's wrist, making his hand twitch.

We decided to test our brain-to-brain interface by seeing if we could play a simple two-player video game. After students in our labs spent months writing computer code and integrating the technologies, on August 12 of last year we finally tried out our setup. Rao took on the role of the sender of information, and Stocco assumed the part of the receiver.

In the game, a pirate ship is shooting rockets at a city. The goal is to fire a cannon to intercept each rocket. Rao alone could see the screen displaying the game. But only Stocco could press the button to fire the cannon. At just the right moment, Rao had to form the intention to shoot, and a few seconds later Stocco would receive the intention and press the button.

Rao donned a tight-fitting cap studded with 32 electrodes, which measure fluctuations in electrical activity at different locations across the head. At any given time, distinct populations of neurons may be oscillating at many different frequencies. When he imagined moving a hand, the EEG electrodes registered a telltale signature that our software could detect. The giveaway was a drop in the low-frequency oscillations in Rao's brain. We used that signature as our cue to send a command over the Internet to stimulate Stocco's brain.

Stocco did not register the impulse consciously, but his right hand moved anyway. The stimulation caused his hand to lift, and when it fell it hit a keyboard and fired the cannon. Success! For the first time, a human brain had communicated an intention directly to another human brain, allowing the two brains to jointly complete a task. As we played the game, we got better and better, to the point where in our last run, we intercepted the pirate rockets with almost 100 percent accuracy. Rao learned how to imagine moving his hand in a consistent manner, giving the computer a chance to make sense of his EEG brain data. Stocco found that he did not know his

THE AUTHORS

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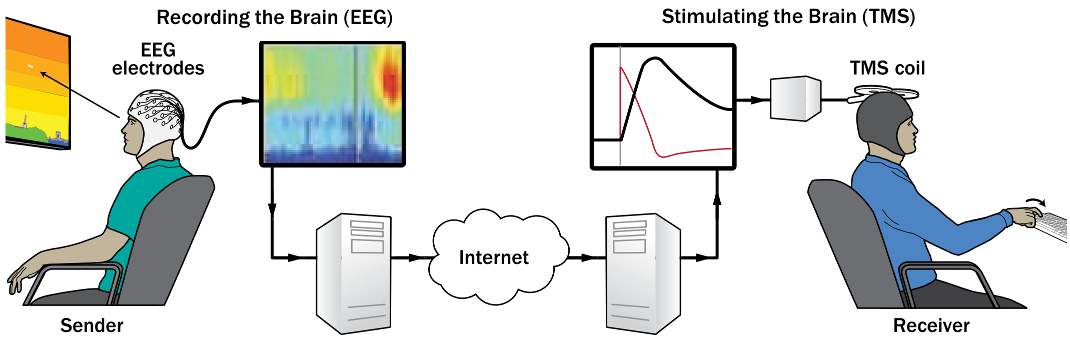
ANDREA STOCCO is a research assistant professor in the department of psychology and the Institute for Learning and Brain Sciences at the University of Washington.

PRECEDING PAGES: COLIN ANDERSON *Getty Images*

To play a computer game with brain waves alone, one person imagines making a move. An EEG cap registers that neural activity. A computer triggers stimulation of a second player's motor cortex, which causes one hand to lift and hit a key.



wrist was moving until he felt or saw his hand in motion.

We have now replicated our findings with several other pairs of humans. Not every trial went perfectly in these experiments, but in all cases, whenever an intention was correctly detected by the EEG system, the information was communicated directly to the receiver's brain using TMS. Throughout the experiment, both subjects were conscious of each other's roles and willingly cooperated to solve a mutually agreed-on task. When a pirate rocket gets hit, the sender knows that his or her partner's brain enacted a movement in response to the sender's own brain activity. We believe this conscious cooperation between subjects is the ultimate goal of true brain-to-brain communication, something that may be hard to achieve with animal studies.

One weakness of our pilot study is that the receiver is passive, essentially lending a hand to the sender's brain. Our next set of experiments will explore targeting other brain regions to produce a conscious thought. For example, we believe we can send visual, as opposed to motor, information from one brain to another—imagine a recipient suddenly seeing the color green and knowing that the hue means he or she should perform a certain action. Indeed, in August one group of scientists used the same technologies as we did to send a crude visual message from one human to another.

Such simple experiments might seem a long way from the complex thought sharing of a Vulcan mind meld, but we believe it is important to begin with a good understanding of how sensory and motor information can be shared. We know much more about how the brain represents sensory and motor signals than about how it encodes complex ideas, such as how to solve differential equations or which city is the capital of Latvia. In addition, many scientists now believe that sensory and motor information are the building blocks of more complex knowledge. We can only venture into transferring bigger concepts after we have mastered simpler forms.

What the Future Holds

We envision several scenarios in which such technology might one day be used. People undergoing rehabilitation, for example, could receive direct guidance from a therapist to speed up their recovery. Those who are paralyzed and unable to speak could use it to communicate their thoughts and feelings directly to loved ones. As brain-to-brain technologies develop, people may adopt them to solve the challenges facing humanity by literally putting their heads together.

Enhancing the brain's abilities with technology is itself not new, of course. We have augmented our physical abilities using automobiles and airplanes, our memories using books and the Internet, and our analytic and communicative abilities using computers and smartphones. Brain-to-brain communication might amplify the social side of our nature—our core tendency to share thoughts with one another.

If scientists and engineers eventually achieve true brain-to-brain communication, the ethical implications will be enormous. All technologies, from the humble kitchen knife to sophisticated genetic engineering, can be used to do good or abused to cause harm. Brain-to-brain communication is no exception. Many a science-fiction plot has benefited from larger than life villains abusing brain implants for nefarious purposes. Security and privacy, already of paramount importance in today's world of highly connected devices, will also be critical factors in any future era of linked-up brains. Neurosecurity researchers will need to minimize the risks of brain-to-brain technology by developing highly secure communications protocols, and policy makers will need to pass laws to minimize any possibility of abuse.

Ultimately we must ask ourselves: Do the benefits of brain-to-brain communication outweigh its risks? How will it shape the evolution of humans? Will it transform society for the better? As our little experiment demonstrates, we need to begin debating these questions now. M

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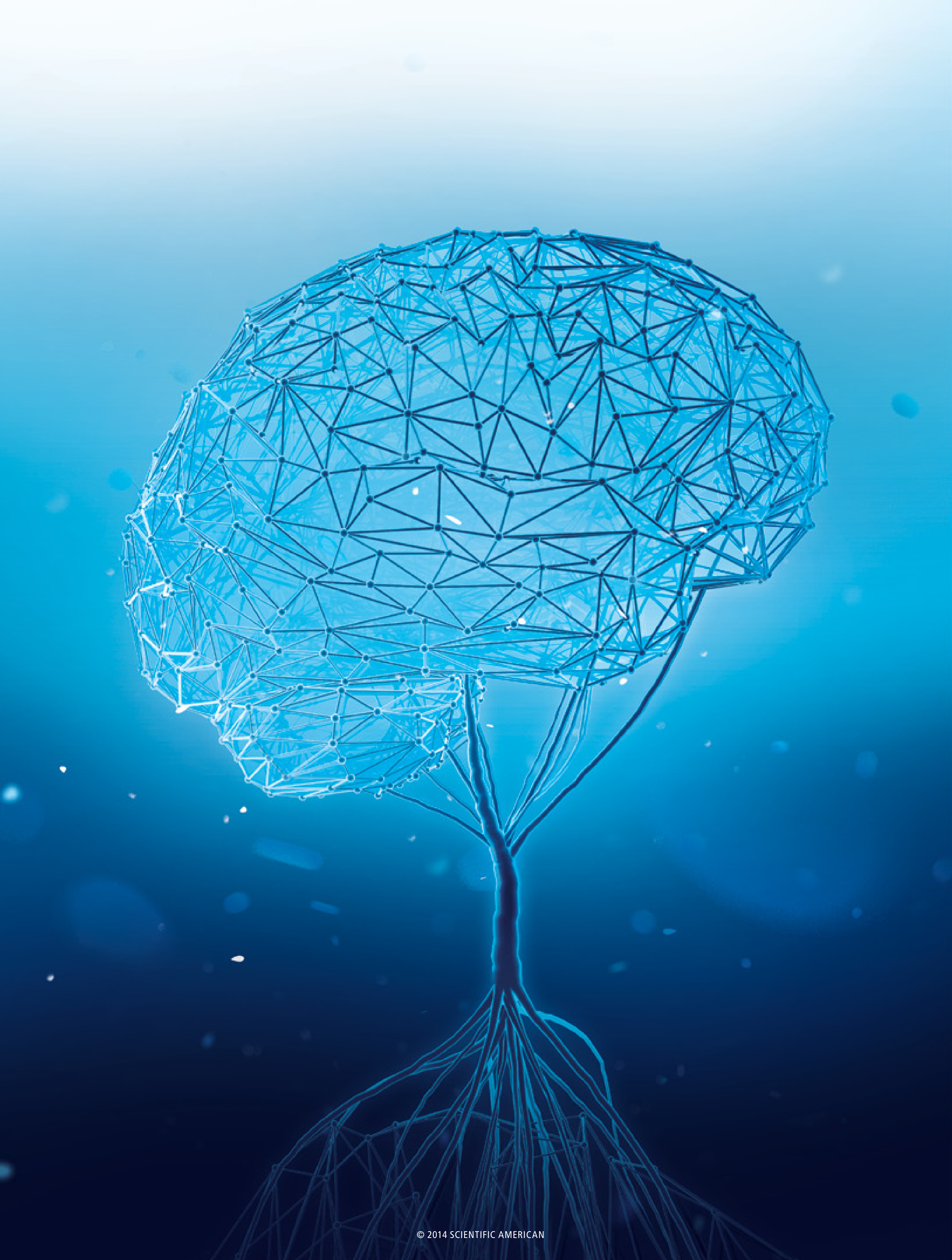
TAMI TOLPA

DECODING THE BRAIN

New technologies are extracting detailed data from our brains that reveal what we know, have seen or have dreamed. Some of the signals could even fly a plane

By Larry Greenemeier

Illustration by **VAULT 49**



In one experiment, test pilots wore caps studded with electrodes that picked up their brain waves. So outfitted, these volunteers learned to adeptly fly—and land—simulated aircraft using their thoughts instead of their hands.

A pilot sits in the cockpit of a Diamond DA42 light aircraft, mentally working through the steps needed to safely land on the runway ahead. Moments later he touches down without having laid a hand on the controls or stepped on the aircraft's pedals. He is no ordinary pilot—in fact, he is not a pilot at all, and he has just landed his aircraft using brain waves.

In a series of experiments earlier this year, seven people with varying degrees of cockpit experience—including none—successfully flew and landed a simulated DA42. Instead of developing the normal hand and foot coordination through hours of training and cockpit experience, these pilots relied on an electrode-laden cap that collects their neural impulses and flight-control algorithms that convert them into commands for a virtual twin-engine aircraft.

Experiments such as this one, which was led by aerospace engineer Tim Fricke of the Technical University of Munich in Germany, are pushing the limits of electroencephalography and other scanning technologies' ability to detect, decode and harness the brain's neural impulses. Where once EEG simply measured the brain's electrical signals as detected on the surface of the skull, the latest EEG headsets and computer algorithms can translate neuronal signals into specific actions that control a variety of mechanical devices, including wheelchairs, prostheses and now flight simulators. Such devices promise to take human performance to new levels.

Some of the EEG-connected pilots, for example, landed their simulated aircraft in dense, albeit digital, fog. Test subjects stayed on course with enough accuracy to, in part, fulfill the requirements needed for a pilot's license.

Other brain-decoding projects rely on a different technology, magnetic resonance imaging, which researchers have used to reconstruct images of faces a person has seen and to probe the content of sleepers' dreams. Although EEG excels at detecting the timing of brain signals down to milliseconds, it falls short in discerning their origins. Functional MRI systems, on the other hand, pinpoint the location of neural activity by registering the relatively slow changes in brain blood flow. By combining these systems, as scientists are now beginning to do, we can better understand what is happening in our brains when we process images, store memories, or make a snap decision such as swinging a bat at a fastball.

Brainflight

In a typical EEG setup, scientists position dozens to hundreds of small electrodes at various locations on a person's skull. These electrodes pick up the electrical signals that pulse through our heads at different frequencies as our brain cells communicate. As with all brain-scanning technologies, EEG relies on software to interpret brain waves. Not all brains behave alike, so the software must process reams of neural data before it can identify patterns in brain activity, a process known as machine learning. Once the system is up to speed on a particular person's neural patterns, it can convert them into useful control commands—say, turning a virtual aircraft left or right or moving a computer mouse. As these algorithms' ability to interpret neural signals improves, scientists can wield brain waves in new ways.

The German researchers began their simulated flights of fancy in January 2014. The experiments, published this past fall, were part of a European project called Brainflight, the goal of which was to determine whether neuroscience and neuroengineering could deliver an aircraft flown solely by signals emitted by the human brain. This extreme goal was made in the service of a few more practical ones: simplifying cockpit instrumentation by using a brain-computer interface (BCI) to replace dozens of buttons and levers; reducing the time and cost it takes to train pilots; and opening up piloting as a possible career path for people with physical disabilities.

During virtual flights, the simulator periodically instructed test pilots to mentally direct their aircraft toward a given heading, much the way an actual pilot must repeatedly make course corrections en route to a destination. The

FAST FACTS
SCANNING OUR THOUGHTS

1. The latest computer algorithms can translate neuronal signals into actions that control mechanical devices, including wheelchairs, prostheses and now flight simulators.
2. Magnetic resonance imaging has enabled researchers to reconstruct images of faces a person has seen and to probe the content of people's dreams.
3. Combining functional MRI with electroencephalography holds enormous promise for revealing clues to the processing of cognition and emotion in the human brain.

COURTESY OF A. HEDDERGOTT *Technical University of Munich*

EEG setup determined within a fraction of a second what each pilot wanted to do and sent those commands to the flight-control system. "We hope that by using BCIs, flying can one day become like hands-free bicycling, where you still have to concentrate on where you want to go [and] on the surrounding traffic but not on controlling your vehicle," Fricke adds.

Such flight simulations have advanced the development of BCIs, which enable the brain to communicate with an external device using thought alone. Most headsets communicate only intermittently with their host computers. This BCI, however, continuously sends information about each pilot's neural activity to the simulator, giving navigators greater control over their virtual flights. With improved software, brain-based command of any complex machinery—including automobiles—becomes a possibility.

Unlocked

Whereas neuro-airline pilots showcase the ability of EEG to extract simple motor commands, other EEG setups can ferret out surprisingly specific information in a person's mind. In an experiment published in 2012 computer scientist Ivan Martinovic, then at the University of California, Berkeley, and his colleagues asked 30 healthy individuals to don EEG headsets and watch a screen on which the researchers flashed images of ATM machines, debit cards, maps, people, and the numbers 0 to 9 in random order. Researchers then studied the EEG data for peaks in neural activity. Such upticks suggested that the person might be familiar with a particular digit or image. From those peaks, software tried to extract personal information, such as a person's ATM PIN code, month of birth, bank location and the type of debit card he or she used. The accuracy of these predictions varied—the correct answer was found on the first guess 20 to 30 percent of the time in the case of the PIN code, debit-card type and bank location. The software guessed the right birth month for nearly 60 percent of the participants.

The point of these experiments was to study possible nefarious BCI use, yet the work also highlights the technology's potential for extracting information from people unable to communicate in other ways. Medical researchers already use BCIs to help people who are locked in—unable to move or speak because of complete body paralysis. In the past, this technology has been able to glean simple yes-or-no answers from these individuals. New EEG algorithms might soon allow them to relay simple requests, needs or other information, says study author and cognitive neuroscientist Tomas Ros of the University of Geneva.

Although the algorithm used in that study requires the consent of the person whose brain is being tapped, coarser types of information might be extracted without a user's awareness. In a study published in 2013 security analyst Mario Frank of the University of California, Berkeley, and his colleagues flashed images of faces in front of participants so briefly that the viewers could not consciously process them. The software could nonetheless determine whether an individual recognized the person in the image 66 percent of the time.

Although such findings might raise the specter of surreptitiously spying on people's inner lives, they also could be parlayed into a useful monitoring tool for individuals suffering from cognitive or emotional disorders. A mobile EEG headset might, for instance, detect confusion in a person with Alzheimer's disease and send a signal to a head-mounted display resembling Google Glass. The display would respond with images or information related to whatever the user is viewing. For a less impaired individual, Ros suggests, such a device might detect a tip-of-the tongue moment and offer up the missing information.

Facial Reconstruction

The signals that EEG electrodes detect represent the brain's internal workings only roughly. For one thing, the skull blocks some of the electrical energy from reaching the scalp electrodes. Further, the signals are too diffuse to trace to their origin. To locate brain activity, scientists rely on fMRI. When neurons are active, they need oxygen, which they pull from the blood. The result is a local change in blood oxygen levels that an fMRI machine can detect.

Scientists have turned to fMRI as a tool for investigating how the brain processes language, learns and remembers, among other functions. Yet the technology is beginning to extract increasingly detailed forms of data from the brain. In one of the latest advances, scientists used brain activity recorded from people undergoing fMRI scans to, for the first time, accurately reconstruct pictures of faces a person had seen.

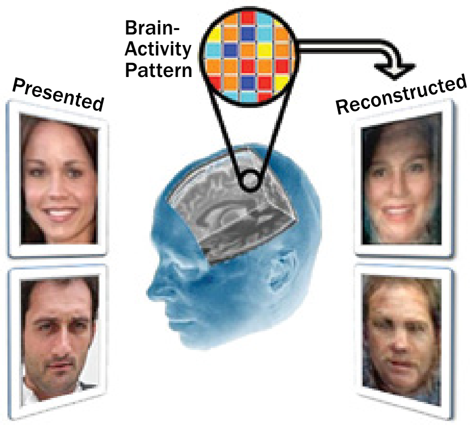
Earlier this year cognitive neuroscientist Marvin Chun of Yale University and his colleagues showed six individuals 300 distinct pictures of faces while they captured the viewers' brain activity. The researchers' machine-learning algorithm correlated both the faces as a whole and their individual features with patterns of blood oxygen levels. They then showed these participants 30 new faces. The software matched the brain activity elicited by the new visag-

The simulator periodically instructed test pilots to mentally direct their aircraft toward a given heading, much the way an actual pilot makes course corrections.

es with the catalogue of neural responses it had created during the original test. Using just the neural activity, the software re-created the faces that the individual had seen. The result was "strikingly accurate neural reconstructions" of the new faces, the researchers wrote in July in the journal *NeuroImage*.

Instead of relying on activity in the brain's occipital cortex, which plays a central role in processing images, these reconstructions were based on more distributed patterns of neural activity, much of it in high-level brain areas that identify and characterize objects by their general properties. The scientists were hunting for more abstract representations of the imagery rather than visual cues such as contour and shading. The researchers next want to investigate how memory, emotion and social judgment, the province of other brain regions, interact with vision to better understand how we perceive faces and objects.

Scientists have also used fMRI and pattern-recognition software to decode some of the content of people's dreams. In work published in 2013 neuroscientist Yukiyasu Kamitani of Japan's ATR Computational Neuroscience Laboratories and his colleagues asked three men to view objects in different categories—such as a person, word or book—while scanning their brains using fMRI. The men, who also wore EEG headsets, were then asked to sleep in the scanner for about three and a half hours at a stretch over seven to 10 days. The researchers awakened the volunteers up to 10 times an hour and asked them what they had seen in their dreams. The software detected a close match between brain-activity patterns collected during dreaming and those assigned to an appropriate object category at least 60 percent of the time.



Computer software can learn to translate the brain activity elicited by viewing a face into a picture of that visage (*left*). When people viewed 30 images of faces, six of which are shown above, a computer reconstructed each face from patterns of blood oxygen levels in the brain (*bottom row*).

COURTESY OF ALAN COWEN

Training the software to recognize a greater variety of categories—including actions and emotions—might reveal even more nuanced information about people's dreams. These findings could then provide clues to how sleeping and dreaming affect memory and mood.

The computer technology used to deconstruct images in detail, whether in dreams or while awake, has very broad applications. "Advancing our ability to decode brain activity and link it to behavior is the fundamental goal of cognitive neuroscience," Chun says, "and it is the foundation for all kinds of clinical—diagnosis, prediction and treatment—and practical applications, including brain-machine interfaces."

NeuroScout

As powerful as it is, fMRI has limitations, too. Multimillion-dollar MRI machines weigh several tons and require subjects to lie still in a narrow porthole while the noisy magnets do their work—hardly conducive to everyday situations. The technique also picks up neural activity relatively slowly, during seconds or minutes. As a result, fMRI cannot reveal the order in which different brain regions spring to life in response to stimuli. EEG, in contrast, can detect changes during milliseconds, closer to the speed of neural changes themselves.

Because the technologies are complimentary, combining fMRI with EEG holds enormous promise for revealing clues to various cognitive and emotional processes. To decode how our brains reorient our attention, for example, these scanning technologies might compare which brain areas light up at a moment of alertness with the pattern of activation when our attention wanders. "We might be able to create systems where, if we track those states, we know when to give somebody important information," says biomedical engineer Paul Sajda of Columbia University. Such a system might warn inattentive drivers when they approach an intersection, for example.

But one of the first applications for this combination strategy is baseball. Sajda and his colleagues have spent the past few years combining EEG and fMRI in real time to study how quickly

THE AUTHOR

LARRY GREENEMEIER is an associate editor at *Scientific American.*

a baseball player can identify a type of pitch and decide whether to swing. In 2012 Columbia postdoctoral fellow Jason Sherwin and graduate student Jordan Muraskin developed a computer program that simulates pitches from a catcher's perspective. They had participants lie in an fMRI scanner wearing a 43-electrode EEG headset while they viewed a simulated oncoming baseball—a dot that expands as it moves to create the impression of a ball approaching at upward of 80 miles per hour. Initially they tested nonplayers, asking them to tap a button if the pitch they saw matched the one they were told to look for: either a fastball or a slider, which curves.

Later, they tried the experiment with players from Columbia's baseball team, who showed greater activation than nonplayers in certain brain regions that are indicative of expertise, Muraskin says. The precise differences in reaction times and location of brain activity between players and nonplayers—something the researchers will reveal in a forthcoming paper—could help poor performers by mapping the brain regions that are underactive compared with those in experts. Stimulating those regions through specific exercises could help laggards improve their pitch recognition and reaction time.

The EEG data could also quantify changes in reaction time so that a player can track how well different training methods are working. The researchers have founded a start-up, NeuroScout, to market the results of their analyses to sports teams.

Universal Decoder

So far algorithms that can interpret brain signals must be trained to recognize each person's idiosyncrasies, a process that can take minutes to hours, depending on the task. After all, an individual's brain and patterns of thought—even in response to the same stimuli—are unique. "If you mapped one person's brain really well, you could build a really good brain decoding device for that person," says psychologist Jack Gallant of U.C. Berkeley. "If you try it on someone else, that person's brain is different," so it will not work well, if at all.

Researchers would like to create more versatile algorithms—ones that require very little, if any, tweaking between uses and users. Such universal brain decoders would drastically reduce the amount of training time in experiments, speeding efforts to understand neural activity across large populations under a variety of circumstances. More robust software would also very likely lead to more reliable EEG-controlled devices.

Most neuroscientists agree that an effective universal decoder is years away. Companies such as Emotiv and NeuroSky make consumer BCI gaming headsets and biosensors with a handful of electrodes that can be shared among users and do not take long to calibrate. They detect only the strongest signals and, as a result, have limited capabilities. Another example of a basic universal decoder is on display through January 4, 2015, at New York City's Discovery Times Square, where Marvel's Avengers S.T.A.T.I.O.N. exhibition gives fans the ability to experience an interactive head-up display similar to Iron Man's. A three-electrode wireless EEG sensor activates the display when a visitor presses his or her forehead against it. The sensor also helps users navigate the display to watch video clips, play games and see their brain waves in real time, although eye-tracking sensors and software also assist with the navigation. The system was built with redundancy to ensure that it worked reliably for the large crowds visiting the exhibit.

Iron Man's complicated hands-free flight-control system might be out of reach for now, but Fricke and his colleagues are making progress getting their system off the ground. The German researchers say they are cutting down the amount of training their simulator software requires—a big step toward unlocking the black box between our ears and extending its power beyond the body. M

"We might be able to create systems where, if we track [mental] states, we know when to give somebody important information," says one biomedical engineer.

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VIRTUAL ASSAULT

Cyberbullies take advantage of the unique psychology of online communities to attack, intimidate and hurt others. Here is what makes trolls tick—and how to stop them

By Elizabeth Svoboda

Illustrations by **FRANK STOCKTON**

When 25-year-old Caitlin Seida dressed up as Lara Croft from the movie *Tomb Raider* one Halloween, she posted a picture of herself enjoying the night's festivities on Facebook. At most, she figured a few friends might see the photograph and comment.

The picture remained in Seida's social circle for more than three years. Then one day in 2013 a friend sent Seida a link with a cryptic note: "You're Internet famous." Clicking the link took her to a site called the International Association of Haters, where her Halloween photo—which she had posted publicly by mistake—bore the oversized caption "Fridge Raider." Hundreds of commenters dragged Seida through the mud for wearing a skimpy costume while being overweight. "Heifers like her should be put down," one commenter wrote. "What a waste of space," another piped in.

Horrified, Seida did some more quick searches and realized her photo had gone viral, racking up poisonous comments on dozens of sites. Reading the messages was like absorbing a series of body blows. "I felt like shit," Seida says. "I cried and cried and cried some more." With a paralegal friend's help, she contacted Web site owners to get the offending images and posts taken down, but she knew her efforts would likely fall short. "I can herd cats more easily than I can control what's posted online."

Despite the publicity devoted to teenage cyberbullies, online aggression is hardly confined to the high school set. About one in four adults has been cyberbullied or knows someone who has, according to a recent poll by the online design firm Rad Campaign, along with Lincoln Park Strategies and Craigslist founder Craig Newmark. The abuse can come in the form of insulting e-mails, tag team–style pile-ons in Internet forums or personal attacks in news article comment sections. Victims are often so profoundly affected that they descend into depression or even contemplate suicide. Yet the problem has largely gone unaddressed because so few observers take it seriously and because it can be unclear which comments qualify as bullying. "People are reluctant to report it," says Chris Piotrowski, a cyberbullying expert and research consultant at the University of West Florida. "A lot of them feel like, '[If] I go to the police, what are they going to do?'"

Researchers are uncovering the psychological forces behind such poisonous verbiage and the harm it causes, and their work points to ways of preventing vicious avalanches of verbal aggression—or at least minimizing the damage. An important part of the solution involves all of us. As members of the Internet democracy, we each have the power to redirect negative group tendencies in ways that promote online civility. "Don't wait for the other two or 300 [people] to do something," says Mary Aiken, director of the CyberPsychology Research Center at the Royal College of Surgeons in Ireland. "It's up to users to create a better environment."

"They got the better of me, and they won"

The trope of the swaggering bully is almost as old as human history. Whether children or adults, bullies blast their targets with scathing words and profane put-downs—and they do not let up, even when the victim begs for mercy. Bullying behavior probably has evolutionary roots, argues social anthropologist Christopher Boehm of the University of Southern California. Early humans who were good at lording it over others enjoyed a boost in their social standing, and as a result, they produced more offspring.

Contrary to popular wisdom, bullies are not merely compensating for their own low self-esteem. In a 2013 study of thousands of middle school students, psychologist Jaana Juvonen of the University of California, Los Angeles, and her colleagues found that bullies are often perched at the *top* of the social hierarchy and demean others to cement their position. Upbringing also plays a key role: ac-

FAST FACTS
CRUELTY IN THE CLOUD

1. About one in four adults has experienced online abuse or knows someone who has.
2. Victims of cyberbullying may descend into depression, suffer symptoms of post-traumatic stress disorder and even contemplate suicide.
3. All of us can curb cyberbullying by reaching out to the victims and expressing our disapproval of online potshots and attacks.

Reading the poisonous posts was like absorbing a series of body blows. "I cried and cried and cried some more," one victim says.

cording to social learning theory, we learn how to interact with others by observing those close to us. Aggressive parents and other role models, then, may produce aggressive kids. The fallout can be devastating: bullying victims suffer significant distress, sometimes for decades. The U.S. Secret Service reports that in most school shooting incidents, shooters felt persecuted or bullied before launching their attacks.

Now that people are socializing in virtual realms, an age-old dynamic has taken hold in a new environment. Cyberbullying is usually defined as intimidation, hurt or harassment conducted using cell phones, the Internet or other electronic devices, but as Piotrowski points out, the contours of this definition are somewhat blurry. "What defines cyberabuse? To one person, it's someone who's being rude. To another person, it's an offensive statement. Another person might say it's [an attack that's] escalating."

At its most obvious, cyberbullying is extremely brutal. Women's-rights activist Caroline Criado-Perez endured dozens of unhinged online trolling attacks from woman haters after she convinced the Bank of England to feature Jane Austen on its 10-pound note. "I remember the man who told me a group of them would mutilate my genitals with scissors and set my house on fire while I begged to die," Criado-Perez told the *New Statesman* in January. "I remember the fear, the horror, the despair. I remember not being able to sleep. I remember thinking it would never end." (Although Criado-Perez did contact the police, she felt they did not take her complaints seriously.)

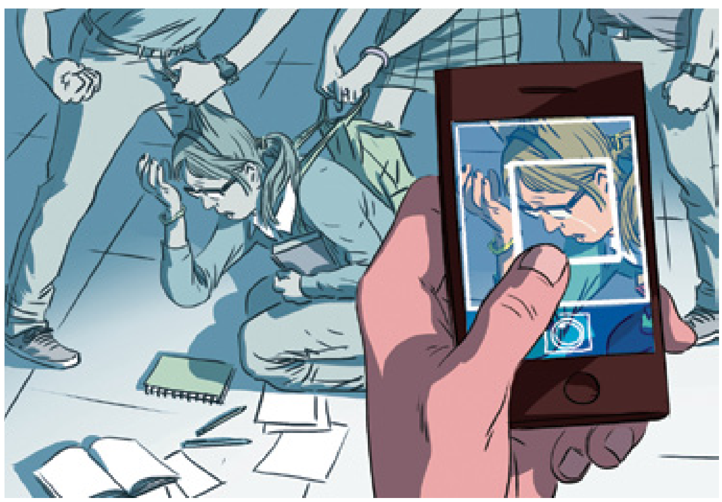
As Criado-Perez's experience suggests, online persecution can take an outsize toll on mental health. Victims of cyberabuse often show symptoms consistent with post-traumatic stress disorder, including flashbacks, runaway anxiety, guilt or depression. They report low self-esteem and feelings of helplessness. "It's a serious problem that has serious psychological consequences," says social psychologist S. Alexander Haslam of the University of Queensland in Australia. Even people used to the public eye may reach a breaking point when tormentors go too far. Australian journalist Charlotte Dawson—herself an antibullying activist—broke down earlier this year after absorbing a relentless barrage of Twitter messages mocking her depression and encouraging her to kill herself. She was found dead in her Sydney apartment, where she had hanged herself. "It just triggered that feeling of helplessness when the trolls got to me," Dawson said in a 2012 interview on Australia's *60 Minutes* after a previous round of Twitter attacks. "They got the better of me, and they won."

Mob Mentality

Just like real-world bullies, the worst online gangsters often display antisocial personality traits. Some may show characteristics of psychopathy such as aggression and disregard for fellow human beings; others are sadistic. In a 2014 study psychologist Erin E. Buckels of the University of Manitoba and her colleagues surveyed more than 1,200 Internet users and found that those who agreed with statements such as "I enjoy making jokes at the expense of others" and "I enjoy playing the villain in games and torturing other characters" were more likely to show traits associated with personality disorders. It stands to reason that people who have real-life antisocial tendencies might show similar contempt for others in the online realm.

Still, plenty of psychologically balanced adults take online potshots at others, says psychologist John Suler of Rider University, partially because cyberspace lets them create a virtual persona that is

With a few clicks, an act of bullying can now quickly spread through the cloud.



separate from their everyday identity. They know that when they retreat behind the cloak of anonymity, they probably will not have to answer for their actions. The phenomenon of the faceless, nameless online bully is a familiar one; surveys suggest only about one in four online bullying victims know their attackers in real life. "From the abuser's point of view, [online bullying] is low risk, high reward," Piotrowski says. "They're thinking, 'I won't get caught because it's online,'" and they get the buzz of feeling elevated because they are pushing someone else down. In a 2012 study psychologists Noam Lapidot-Lefler, now at the Max Stern Academic College of Emek Yezreel, and Azy Barak of the University of Haifa instructed participants to debate a contentious topic in pairs over online chat; they noted that people were more likely to threaten their debate partners when posting under an alias than when using their real names.

But the most noxious and prevalent instances of online bullying emerge from a combination of anonymity and group forces. In 2001 social psychologist Tom Postmes, now at the University of Groningen in the Netherlands, and his colleagues reported that when online participants were anonymous, they were more likely to conform to the behavior of the groups they belonged to—a tendency that is problematic when the group's members are rude or aggressive. Similarly, in a 2012 study psychology researcher Adam Zimmerman of the University of North Florida studied 126 online participants in a word-unscrambling game and found that those who did not use their real names were more likely than identified participants to write aggressive blog posts about their fellow players, especially when they observed other participants acting aggressively. "We get permission [to bully] from the people around us," Zimmerman says. "It gives us the idea that we could also do that if we want to."

When nameless, faceless online participants assume the identity of the group that surrounds them, a virtual mob mentality takes hold. People are impulsive and aggressive and tend to copy one another, often leading to tag-team attacks like those hurled at Seida. "When people engage in online bullying, they are often doing it in front of a particular audience they imagine is approving," Haslam says. If a chat forum's terms of engagement—stated or unstated—allow people to be bullied without consequence, new participants are probably going to conform to the norms set by the bullies. Even people with good intentions can succumb. "If others are piling on someone, you might join in even if you weren't setting out to hurt anyone," adds psychologist Scott O. Lilienfeld of Emory University.

"They're thinking, 'I won't get caught because it's online,'" and they feel elevated because they are pushing someone else down, says one cyberbullying expert.

Once insult-slinging gets under way in a chat room or e-mail thread, it can escalate quickly, perhaps because empathy is more elusive in a virtual environment. Cyberaggressors cannot see their victims' tears or the fear in their eyes. Their targets are abstractions. In addition, the bullying persists in ways that would have been unthinkable in the era before Google and Facebook. Victims relive that punch-in-the-gut feeling every time humiliating photos of them appear on a new Web site or insults appear in search results for their name. Also, as Seida learned, erasing the attacks or even getting bullies to admit to the harm they have caused is fiendishly difficult. When Seida and a friend tracked down some of her tormentors and sent them personal notes, they were rebuffed. "We sent them messages and a little certificate that said, 'Why don't you be a human being and take down the comments you made?' Nobody apologized."

Bullying can affect bystanders, too. In a study published in 2013 Colorado State University communications specialist Ashley Anderson and her colleagues recruited more than 1,000 people to read an online article about the risks and benefits of nanotechnology. Readers who were exposed to "flame wars" in which commenters slammed nanotech or insulted its defenders tended to see nanotechnology's risks as more pronounced than did readers who had *not* seen such verbal attacks, regardless of whether the arguments held water. If, as these results suggest, bullies' comments are often persuasive, passive observers might start to buy into some of the attackers' claims ("Theresa is a slutbag ho").

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Setting New Norms

The toxic fallout from online attacks has led some respected news outlets to kill off virtual discussion communities. "We are as committed to fostering lively, intellectual debate as we are to spreading the word of science far and wide," wrote *Popular Science*'s then digital editor Suzanne LaBarre last fall, announcing that the magazine planned to eliminate its Web site's comment section. "The problem is when trolls overwhelm the former, diminishing our ability to do the latter."

The decision by *Popular Science* to nix online comments provoked outcry. Efforts to curb online bullying and flame wars often err in the direction of limiting open discussion. Part of the reason is practical. Policing individual online interactions—by, say, enforcing language restrictions on discussion boards or cleaning up news comment sections—can be a time-consuming task for Web site managers. What is more, few victims report bullying to site administrators because they think nothing will be done about the problem or because they fear retribution from attackers.

So far legislative solutions to the online aggression problem do not seem all that effective, even though 48 states have laws against electronic harassment. California's legal code, for instance, gives administrators grounds to suspend or expel students for participating in online bullying, and Louisiana's legal code reads, "Whoever commits the crime of cyberbullying shall be fined not more than five hundred dollars, imprisoned for not more than six months, or both." Such laws, however, are seldom enforced, in part because cyberbullying victims do not always report being abused—and when victims *do* complain, administrators and discussion board owners do not always notify state authorities.

In the absence of systematic policing by Web site managers or the government, some administrators have begun testing automated antibullying tools. A system produced by the video game company Riot Games, for instance, detects patterns of negative behavior from particular online players and sends them a quick message, gently letting them know they have crossed a line. "For neutral and positive players," Jeffrey Lin, a lead designer at Riot, told *GamesIndustry* magazine, "this subtle nudge is often enough to get them back on track."

Yet some hard-core bullies are unfazed by automated warnings and keep right on unloading their venom. In such cases, community members should step in—whether by writing a response to the aggressor on the forum or reporting bullying comments as abuse. When members of an online forum, discussion group or e-mail thread consistently refuse to tolerate bullying, new participants will probably conform to that established norm, turning the group into a force for good.

All online participants determine what a community's norms are. "If trolls show up, if the community as a whole can say, 'This is not something we want here,' it can convince that person to move on," Suler says. Taking a stand not only helps the victim but is also good for you: when people see others being bullied and fail to speak up, their own psychological health often suffers.

Concerned onlookers can also help curb bullying's spread by reaching out to victims individually via e-mail or direct message. Aggression often begets aggression—cyberbullying victims may turn around and bully others, according to San Diego State University psychologist Jean M. Twenge. But you can mitigate this effect by offering the abused your support and condemning the attacks. In a 2007 study Twenge and her colleagues found that when people made a short, friendly connection with someone else following an episode of social exclusion, the victim was less likely to show aggression

What to Do If You're a Victim

If you have suffered abuse at the hands of cyberbullies, you are not alone. Millions of others have, too. Here are some expert-approved strategies to stop the harassment and minimize its effect on you. —*E.S.*

Don't engage. When the harassment is relatively mild, the old "I can't hear you" approach really can work. Block the person's social media profile or just stop replying to the comments. The troll *wants* you to get worked up. When you don't respond, he or she sometimes loses interest.

Alert those in charge. Report abusive messages that include ad hominem attacks or vulgar language to someone who can make them stop—whether the police or an online forum's administrator. A 2014 survey found that in 61 percent of cases, social networks shut down reported harassers' accounts.

Talk to a professional. If online attacks are bad enough to make you seriously doubt your self-worth, consult a therapist. Cyberbullies are skilled at eliciting a very intense, instant reaction that may be unlike anything else you have experienced. You most likely will need support to deal with it.

afterward. "Having even one person accept you seemed to mitigate the [aggression] effect," says Twenge, author of *Generation Me*. "Reach out and say, 'I'm sorry this happened.'"

Such outreach is especially crucial because even antibullying education may not deter determined trolls. According to a 2013 study by University of Texas at Arlington criminologist Seokjin Jeong and Byung Hyun Lee of Michigan State University, students were *more* likely to be bullied at schools that had installed antibullying programs, perhaps because the programs inadvertently gave bullies ideas for tormenting their victims.

Rallying Friends

Many months after enduring online ridicule, Seida decided she was not going to let the bullies' vile comments define her. To give her detractors the middle finger, she did a boudoir photo shoot while wearing the now infamous Lara Croft costume. "If they're going to talk, I might as well give them something to talk about!" she says.

Seida's brush with cyberbullies inspired her to reach out to others on the receiving end of vicious online attacks. Along with a photographer friend, she created ifeeldelicious.com, a site designed to help victims of online bullying repair the damage to

their dignity and psyche. She and other members ran a successful campaign against a notorious bully they called "the King of Mean," rallying others to boycott and speak out against his insult-ridden Web site and social media sites. She advises people who face relentless online jibes to gather a group of friends who appreciate them. (For additional advice, see "What to Do If You're a Victim," on page 51.) Indeed, knowing someone else has your back goes a long way toward softening the impact of drive-by online attacks. "Talk to somebody—find a support system," Seida says. "If you keep it inside, it's just going to eat you alive." **M**

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A DIGITAL SAFETY NET

People are increasingly broadcasting symptoms of mental illness on social media. We should listen

By Roni Jacobson

Peter's Facebook friends knew something was wrong months before he had a manic episode. He had been posting about expensive shopping trips and name-dropping celebrities he claimed to have partied with—seemingly out of character for the 26-year-old former dental student from Atlanta. When Peter (not his real name) ran away from home in April 2013, he unleashed a flurry of paranoid, all-caps status updates saying his family was out to get him. Meanwhile his sisters left messages on his Facebook wall begging him to come home.

What might have been a family affair a decade ago instead played out in front of hundreds of eyes, as friends and acquaintances watched the saga unfold on their news feeds. Some people sent him private messages. Others posted on his wall. Many commenters expressed support and concern, but a few were mocking and unhelpful. One person wrote "lol." Most people, however, only watched.

Mental health crises such as Peter's are being captured on social media with increasing regularity. Posts on Twitter by actors Charlie Sheen and Amanda Bynes, for example, chronicled their psychological unraveling before millions of followers, sparking intense debate among celebrity watchers about the appropriate reaction to their attention-grabbing tweets.

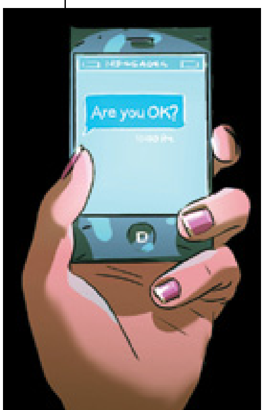
People who witness such events among their own friends face a challenging question: Should they respond—and if so, how? "Mental illness is not like the flu," says computational social scientist Munmun De Choudhury of the Georgia Institute of Technology. Unlike other conditions, "people are often not comfortable discussing these things." The deep-rooted stigma of the topic discourages people from probing the emotional states of others. Yet silence compounds the problem because struggling individuals can come to believe they are suffering alone and avoid seeking help for fear of ridicule.

Social media could radically change this attitude. As people increasingly share very private experiences online, observers are gaining unparalleled insight into one another's mental lives. Digital interactions—through blog posts, social media up-

FAST FACTS
A FRIEND IN NEED

1. Many individuals struggling with mental health issues turn to social media to describe their challenges, yet onlookers are unsure of how to respond.
2. Research indicates that people who post about their difficulties are seeking support and would welcome a friendly, nonjudgmental reply.
3. In blurring the lines between private and public space, social media could help reduce the stigma of discussing mental health.

dates, Instagram photos, and more—produce a wealth of data about a person's emotions and behaviors. Close family members and distant acquaintances alike can glimpse disturbing patterns in these outlets and offer simple forms of support. By breaking the silence, they can ease a colleague's or companion's pain—and they can chip away at the stigma that keeps many from seeking help in the first place.



Social technologies provide a lifeline for people with mental illness to find help.

Emotional Voyeurs

Social media might not seem like a panacea for mental illness at the outset. People often err on the side of silence when a typically private sentiment is expressed in a public manner. In a 2013 study, for example, Megan A. Moreno, an adolescent medicine specialist now at the University of Washington, and her colleagues asked college students whether they had ever seen a Facebook status update from a friend mentioning depression or anxiety. A majority said they had, but when the researchers asked students if they would respond to such a post, they were unsure. Most said they would if the post were written by a close friend or relative but not by a more distant acquaintance. In the latter case, they would expect someone closer to the person in distress to do the heavy lifting.

The students' aloofness may be partly explained by the bystander effect—a psychological phenomenon first proposed in the 1960s, in which people become less likely to intervene in a crisis as the number of witnesses grows. A similar diffusion of responsibility occurs online. In multiple studies, researchers have posed as people requesting help by e-mail and in chat rooms. The findings have been consistent: the bigger the online community, the less likely a recipient is to respond. On platforms such as Facebook and Twitter, where no one knows who has seen what, a sense of personal responsibility may be particularly elusive.

People might also hesitate because they cannot gauge whether a situation is serious, suggests psychologist Jill Berger of the University of Maryland, who has surveyed college students' responses to online signs of suicidal thinking. Although they are concerned, she says, they do not want to "make a big deal" about something potentially mundane and risk an awkward interaction.

Even if a situation is not yet dire, Berger counsels that it warrants follow-up. Social media acquaintances may be critically positioned to offer support. Writing a status update or tweeting about a problem can be easier than talking about it face-to-face, particularly for stigmatized issues such as mental illness. Evidence suggests that people feel less inhibited online. Furthermore, adolescents and young adults, who are at an age when mental disorders typically manifest, are more inclined to disclose sensitive information to peers than to adults.

Moreno believes that these posts are an important outlet for vulnerable individuals. Often, she says, posters are looking for emotional support and encouragement. On Facebook, "you don't have to wait in line for a therapy appointment—you can get that positive feedback within seconds." According to Moreno, posting frequently about mental health problems on social media could indicate that a person is not getting the help he or she needs offline. To a person in crisis, not getting a response may be "almost worse than getting a negative response," she adds, because it seems like "nobody is listening and nobody cares."

Unlocking Support

The work of scientists studying the reticence of onlookers makes it clear that people do hear online cries for help—they just do not know how to reply. The good news is that people can be encouraged to take action. The bystander effect, for example, now appears to be more nuanced than was initially thought. Recent studies have found it to be less powerful than in early experiments, perhaps because people are more aware of it today.

And there may be ways to reduce or even reverse the effects. In a 2011 update on the bystander effect, Peter Fischer, a psychologist now at the University of Regensburg in Germany, and his colleagues analyzed data from all previous studies of the phenomenon and found that it diminishes significantly as the situation becomes more obviously dangerous. When faced with a sure emergency, the self-doubt that holds people back often disappears.

The key to unlocking support is therefore educating people about how serious mental health crises can be, how to spot one and what witnesses can do to help. Mental health "first aid" programs, for

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To a person in crisis, not getting a response may be "almost worse than getting a negative response," Moreno says, because it seems like nobody cares.

example, can teach people how to recognize and respond to a mental health emergency in real life. Certain groups, such as college resident advisers (RAs), traditionally tasked with identifying distressed students, are learning to notice warning signs on social media as well. Moreno thinks that RAs and other youth leaders, such as team captains and church group organizers, are well positioned to detect crises unfolding online and either reach out themselves or pass the information along to a more qualified individual, such as a school counselor.

Meanwhile Facebook is encouraging its users to act when they see troubling posts. In 2011 the company added a tool to anonymously report suicidal content. Once you submit a report, Facebook informs the person in distress that a contact has expressed concern and offers links to emergency hotlines and the opportunity to chat with a crisis worker.

Recipients are, of course, free to decline, but research indicates that most people who post about their troubles do want help. In one of several recent studies, Moreno and her colleagues asked 60 college freshmen how they would like to be treated by someone who saw signs of their depression on Facebook. Almost every student said that they would be open to communication from friends, professors and RAs. More than 30 percent said they would be okay with receiving a message from a stranger.

Most respondents, however, added that they preferred people to contact them directly—either one-on-one, over the phone or via e-mail—and with an open mind. "The emphasis was on this idea of being inquisitive: asking questions rather than making judgments," Moreno says.

In addition, some amount of automated support could help sufferers. Researchers at Harvard University, Dartmouth College and other institutions are now developing apps that monitor smartphone and social media activity to detect signs of distress. This data trail could allow clinicians to intervene before symptoms intensify or send users automated suggestions for how to improve their mood or get back in touch with reality.

Learning to Listen

Beyond offering new lifelines for people under duress, social media may now be lifting the veil of silence that has long shrouded mental disorders. Social scientists have found that throughout history, prejudice is best dismantled when people interact frequently with others unlike themselves. Indeed, a 2012 meta-analysis of approaches to reducing stigma concluded that simply having contact with people with mental health conditions trumps social activism and education in getting adults to abandon their preconceptions.

Social media onlookers might even experience a boost in empathy and feel more willing to reach out after discovering a friend's struggles online. In a 2014 study led by health communication expert Nichole Egbert of Kent State University, students were also significantly more likely to support a depressed friend if they identified with his or her problem.

Along those lines, the New York City branch of the National Alliance on Mental Illness launched a social media campaign called "I Will Listen" in October 2013. In a series of videos and Facebook posts, actress Mariel Hemingway, writer Andrew Solomon and other public figures pledged to listen to those with mental illness "with an open mind and without judgment" and shared personal stories on these issues. Since the start of the campaign, dozens of people have followed suit, documenting their own experiences with mental illness on Twitter, Vimeo and Instagram with the hashtag #IWillListen.

As Moreno sees it, social media "offers us tools that we didn't have 10 years ago," when the same people were walking around with little social support and few opportunities for others to witness their distress. Now that we have the tools, it is just a matter of using them. M

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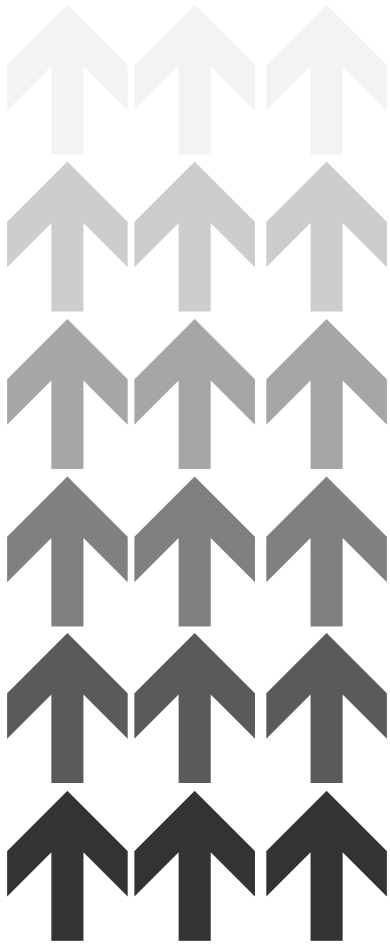
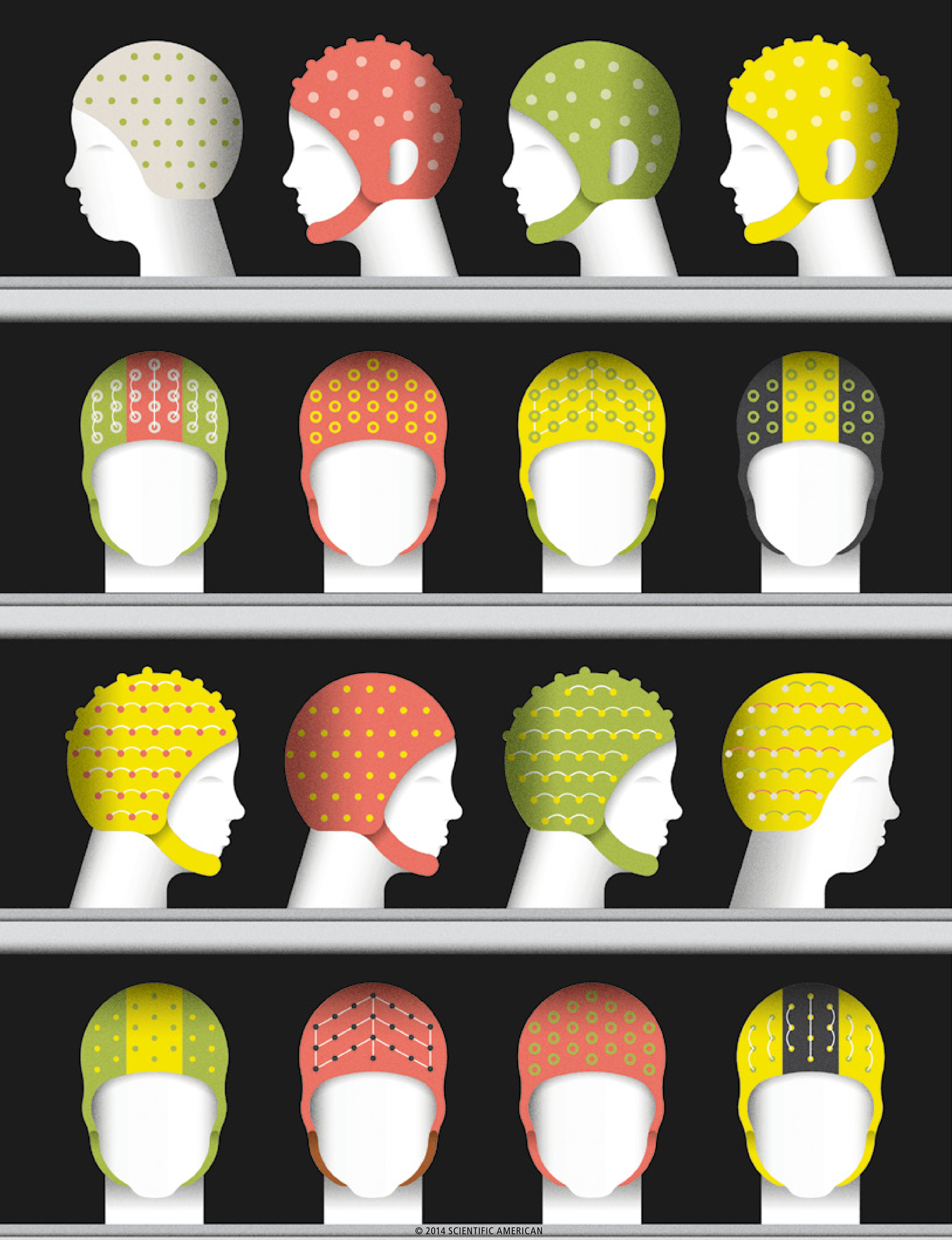


YOUR ELECTRIC PHARMACY

Future medications for brain disorders could be delivered through electrodes rather than pills

By Marom Bikson and Peter Toshev

Illustration by **RADIO**



Your temples throb as you enter the pharmacy. For months you have been battling daily migraine headaches. You have tried your doctor's every suggestion—drinking more water, changing your diet, getting extra sleep—and downing a host of pain pills. Now you are armed with a prescription for a totally different kind of treatment.

The pharmacist guides you to a shelf of headgear, labeled with different brain regions. She fits you for a cap, the underside of which features thin conductive metal strips, called electrodes, coated in adhesive gel to stick gently to your scalp. The electrodes link to a slim cable that dangles from the back of the cap. She then hands over the key component of your prescribed medication: an electric stimulator.

Once a day for the next week you will don the headgear and plug the cable into this device for a 20-minute dose of electricity. Setting aside your trepidation, you give it a try in front of the pharmacist. At first you feel only a tingling sensation and then relief.

As you wear the cap, an electric current is traveling from the electrodes, past hair, scalp and bone, into the brain regions responsible for your migraines. At first it merely blunts the pain, but over time it will also gradually rewire your neurons to prevent future attacks. The pharmacist explains that you will be free to carry on with your day—finish chores, watch television, go for a walk—with the cap on your head, and when the dose is up, the stimulator will simply stop running.

For now this scene is still the stuff of science fiction, but many researchers believe that within the next few years this form of treatment could become commonplace. The technique, called transcranial direct-current stimulation (tDCS), is being investigated for dozens of applications, including helping people recover from brain injury, treating depression, enhancing vigilance and managing pain.

Using electricity to tinker with the brain is nothing new. We have long known that neurons send electrical signals to communicate. In response, scientists have sought to hack these missives to alter or heal the brain. Yet most efforts have been cumbersome, dangerous or costly. In contrast, tDCS is noninvasive, inexpensive, user-friendly and portable. The only known side effects are minor skin redness and irritation, which can be corrected by adjusting the headgear.

In fact, some scientists suspect that tDCS could launch a new era in treatment that could rival traditional drugs. Researchers have spent decades struggling to develop pharmaceutical medicines that can enter the brain and heal it, with only mixed success. Now a growing community of brain scientists hope that electricity might succeed where chemicals have largely failed. At least one company—GlaxoSmithKline—is already funding research into electrical therapies. Clinics and hospitals around the world have begun to offer the technique to patients in need of rehabilitation. The Department of Defense has invested tens of millions of dollars into investigating techniques that can boost cognition in healthy individuals. The media buzz surrounding these developments has inspired a community of hobbyists who are eschewing caution and attempting tDCS at home.

To develop tDCS into a credible therapy and enhancer, scientists will need to answer many lingering questions. They must determine the proper doses of electric current that work best with different ailments. And they must dramatically scale up experiments to clarify the safety and efficacy of these treatments across large populations. Those caveats aside, the growing interest in tDCS suggests patients and physicians are eager for new methods to treat the brain. In a few years' time, small doses of electric current may be just what the doctor orders.

The Brain Electric

The basic components of this technology are straightforward: a power source and a way to transfer electricity into the brain. So simple is the technique that even humans of antiquity explored rudimentary forms of it. In the first century A.D., for example, Roman emperor Claudius's physician applied torpedo fish (electric rays) to the skull to treat headaches. Eighteenth-century electrical discoveries led to more sophisticated experimentation. By 1802 Italian physicist Giovanni Aldini had proposed a treatment for depression that involved tapping a patient's head with direct current from a battery.

The 20th century brought more complex techniques for electrical healing onto the scene. In the 1930s doctors began treating mental illness by inducing seizures with electric

FAST FACTS

IT'S ELECTRIC!

1. Transcranial direct-current stimulation (tDCS) applies a weak electric current to the scalp to modulate signals in the brain.
2. This technique shows promise in treating several brain-based conditions that have stumped pharmaceutical researchers, including migraine pain and depression.
3. Once scientists establish a more uniform procedure and comprehensive understanding of dosage, tDCS could become a widely used therapy.

The technique acts like a volume dial, in which the flow of electric current can either make neurons more active or quiet them down.

shocks. Fifty years later scientists demonstrated that brain regions could be electrically activated either from the outside using large magnets, a technique called transcranial magnetic stimulation (TMS), or with the aid of surgically implanted electrodes. These methods, which involve expensive equipment and in some cases serious side effects, were generally considered procedures of last resort. Drug discoveries, not electrical interventions, were believed to hold the most promise for treating conditions of the brain.

A few researchers nonetheless kept tinkering with a simple form of electrical brain stimulation throughout the 20th century that would ultimately evolve into modern tDCS. The challenge for these pioneers was to find a way to demonstrate and measure the physiological changes this technique could induce.

In 2000 neurophysiologists Michael Nitsche and Walter Paulus of the George August University of Göttingen in Germany developed an ingenious means of doing this. Rather than administering tDCS by itself, they used it to alter the brain's response to TMS, a more established technology. The researchers first placed their participants' motor cortex under a large magnetic coil. This device induced electrical activity in the area that controls movement in a person's right pinky finger. Producing such activity caused the pinky to wiggle.

Nitsche and Paulus also placed two electrodes over portions of the motor cortex and linked them to a battery. Turning it on sent a low amount of current in one electrode, through the skull, into the brain and out through the other electrode. Depending on how they configured the setup, Nitsche and Paulus could change the direction the current traveled through the brain, which they discovered would either intensify or diminish the pinky twitching initiated by TMS. In essence, they could use tDCS to fine-tune the effects of the magnetic coil.

At the time researchers already had a strong understanding of the way TMS altered the brain. As a result, this experiment was able to demonstrate convincingly that tDCS had a real effect on neural activity. Somehow the weak current influenced the behavior of neurons above and beyond the changes expected from TMS.

Nitsche and Paulus suspected that tDCS was altering the way in which brain cells could respond to electric signals. Neurons send and receive information by releasing a spike of electricity through connections called synapses. The signals themselves are created by the movement of charged ions in and out of brain cells. In TMS, the powerful magnet can cause neurons to expel and admit ions, forcing them to fire.

But the current created by tDCS has a subtler effect. It produces a river of charged ions that wends its way through the head and brain in a circuit. As this current flows around and through neurons, it can alternately blunt or enhance their responses to other electric messages. Neurons near the electrode that introduces current into the brain become more sensitive to electric signals. But those near the electrode that removes current are less responsive. Subsequent experiments revealed that this approach could manipulate not only the electric signals from a magnetic coil but also those produced naturally in the brain.

In the 14 years since Paulus and Nitsche's seminal experiment, numerous scientists have confirmed not only that tDCS can change the brain's activity but also that it offers therapeutic benefits. Whereas other electrical approaches effectively kick certain neurons into action, tDCS serves as a volume dial. The flow of electric current in this technique can either make neurons more voluble or quiet them down.

Jump-Starting Health

The ability to dial up or down neuronal chatter offered neuroscientists an abundance of options for treating disorders. The technique could be used to increase signaling that helps to heal the brain or dampen activity that contributes to dysfunction, or both.

The first challenge in using tDCS as a therapy is identifying the best neurons to target for a given problem. Typically multiple brain regions contribute to a disease, which means many different stimulation setups could bring a patient relief. Consider the case of migraine pain. Brain scans of people af-

Researchers use adjustable headstraps (*left* and *top right*) to hold electrodes in place when they administer tDCS. The electrodes are wired to a stimulator device (*bottom right*) to send a controlled dose of electric current into the head and brain.

COURTESY OF LABORATORY OF MAROM BIKSON

flicted with these severe headaches have revealed that before an attack, part of their visual cortex becomes more active. So Paulus and his colleagues decided to see if quieting that area with tDCS could prevent headaches.

In the study, which was published in 2011, 12 migraine sufferers received six weeks of electric stimulation. For 15 minutes a day, three days a week, the scientists directed current to discourage signaling in the migraineurs' visual cortex. The remaining individuals received a sham treatment, in which they merely experienced a tingling sensation. Eight weeks later the researchers followed up with their participants. Subjects who had received the full course of tDCS had shorter migraines, with significantly less pain, than those in the sham condition did. The treatment was not a cure-all—it did not make migraines less frequent—but it seemed to at least soften their blow.

Other experiments, however, have hinted at a different way to assuage migraine pain. Namely, stimulating parts of the motor cortex is known to trigger the release of natural painkillers called opioids. A year after Paulus's migraine study, a second group of scientists, led by University of Michigan pain neuroscientist Alexandre DaSilva and including one of us (Bikson), opted to rev up the motor cortex with electric current. During the course of four weeks, seven migraine patients received 10 sessions of tDCS, 20 minutes each, and five others received sham stimulation. The recipients of tDCS did not experience immediate relief, but in the weeks that followed, they reported less pain than individuals in the sham group, and their relief persisted for months. Ultimately these different approaches may allow clinicians to craft customized treatments for patients.

As both experiments demonstrated, the full effects of tDCS can materialize slowly and endure for weeks or months. This is in part because tweaking the rate at which neurons fire can alter the architecture of the brain in lasting ways. When brain cells activate together, the connections among them grow stronger and more numerous. Cells that seldom fire in concert gradually lose their linkages. Adding tDCS can therefore heighten the brain's ability to rewire itself—its plasticity.

A boost in plasticity can have powerful implications for repairing the brain after damage. During a stroke, for example, the blood supply to a part of the brain becomes blocked, starving neurons and damaging their connections. Through months of rehabilitation, people can relearn lost skills as their plastic brain builds new connections among surviving neurons. Incorporating tDCS could potentially speed up their recovery.

In 2011 Harvard Medical School neuroscientist Felipe Fregni and his collaborators investigated this idea while working with 14 patients who spent two weeks engaging in regular exercises to regain motor control. In addition, the subjects received either 40 minutes of daily tDCS or a sham treatment. Fregni and his colleagues aimed current at injured brain areas in the motor cortex to encourage the growth of new connections. All the patients gained some motor function after two weeks of therapy. Yet the group receiving tDCS recuperated the most. In a sense, tDCS seems to help the brain to help itself.

Many scientists believe tDCS could quell symptoms from a host of conditions, including dementia, epilepsy and schizophrenia.

Rehabilitation and pain management are just two promising avenues of tDCS research. As we learn more about the networks in the brain associated with neurological and psychiatric disorders, many scientists believe the technique could quell symptoms from a host of conditions, including dementia, epilepsy and schizophrenia.

The small, proof-of-concept studies that have occupied scientists for the past decade are now giving way to large-scale, long-term trials. In 2013, for example, University of São Paulo physiologist Andre Brunoni led a six-week, 120-patient trial in which tDCS had comparable benefits to a commonly prescribed antidepressant in treating depression. Brunoni is now expanding his efforts with a pool of 240 patients and other medications. Studies of this kind will be the best way to illuminate the technique's full potential going forward.

Zap to Attention

Aside from tDCS's promise as a therapy, many people have become fascinated by how stimulation could change the lives of healthy individuals. If we can suss out the core networks linked with such abilities as critical thinking and creativity, the logic goes, scientists could give those areas a boost. Or they could dial down unwanted negative emotions and bad habits.

Indeed, growing evidence supports the idea that tDCS could enhance the brain's abilities in domains as diverse as curbing junk food cravings and modifying mood. Several research groups have proposed that tDCS can accelerate an in-

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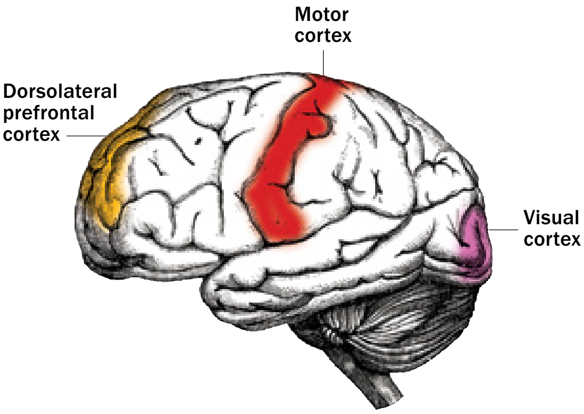

Researchers using tDCS have targeted the visual cortex to treat migraines, the motor cortex for pain relief and rehabilitation, and the dorsolateral prefrontal cortex to improve vigilance.

ISTOCKPHOTO

dividual's ability to master new words and grammatical rules, as well as complex motor tasks such as memorizing an intricate finger-pinching pattern.

These studies are still relatively small in size and their effects are modest. Any attempts to elevate performance using tDCS would almost certainly need to occur in tandem with—not instead of—old-fashioned approaches to learning. Just as Fregni's rehabilitation study coupled stimulation with traditional physical therapy, users seeking cognitive enhancement would still need to avail themselves of lots of practice, exercise and rest.

Yet tDCS might exceed conventional approaches in a few choice areas. In 2014 biomedical engineer Andy McKinley of the U.S. Air Force Research Laboratories published his findings on the use of tDCS in improving vigilance. McKinley's team worked with 30 military recruits who had to endure 30 hours of wakefulness while taking a series of attention tests. Four hours in, the researchers gave 10 recruits a 40-minute session of tDCS and some plain chewing gum. In this case, the team aimed electric current to stimulate activity in the dorsolateral prefrontal cortex, an area supporting many functions, among them attention and working memory.

The remaining recruits had a session of sham stimulation at the four-hour mark, and 10 of these subjects also obtained a stick of caffeinated gum. In this way, McKinley could pit tDCS head-to-head with caffeine, one of humanity's favorite vigilance enhancers. At the end of the trial, the researchers discovered that the group receiving tDCS showed pronounced improvements in their test scores, and this boost in alertness lasted for six hours. Caffeine's kick, in contrast, was less potent and persisted for only two hours. Nothing beats a good night's rest—but perhaps swapping java for a jolt of electricity could someday help the sleep-deprived.

Ready for Prime Time?

Scientists working with tDCS are now at a crossroads. On one hand, researchers are still unraveling the basic mechanisms of tDCS, and on the other, patients, government agencies and companies are angling to bring this technique to the real world.

One of the major remaining questions to address is dosage. Thus far studies have used very weak levels of stimulation to produce modest findings. Scientists now need to figure out where the electrodes should ideally be placed for a given condition, as well as the optimal intensity of stimulation. As with drugs, increasing dosage may improve results—but only up to a point. The conditions for this will be unique to every application, but it is possible that practitioners will at some point face trade-offs. For example, raising current to treat migraines might further diminish a patient's attacks, but the stimulation itself could become increasingly uncomfortable. Without larger trials, we cannot fully appreciate either the limitations or potential of this technique.

Given these known unknowns, the research community is deeply concerned about individuals trying to replicate these studies at home. Although the findings in this field are tremendously exciting, there is still much more we have to learn about electric stimulation. In the interim, the public and scientists alike must approach the hype surrounding tDCS with care.

As long as we balance our optimism with caution, however, this research offers enormous benefits. The surge of interest in tDCS has even sparked studies of other bioelectric therapies, such as techniques that apply alternating or pulsed current, which can offer unique benefits to the brain. All these advances could pave new routes to self-improvement. Millions of people who struggle with conditions that have long eluded treatment, such as chronic pain and depression, may finally be aided. To achieve this outcome, clinicians will have to adopt electrical stimulation in their practice. A little further out, putting on a cap for healing and thinking may become as commonplace as popping a pill or sipping your morning coffee. **M**

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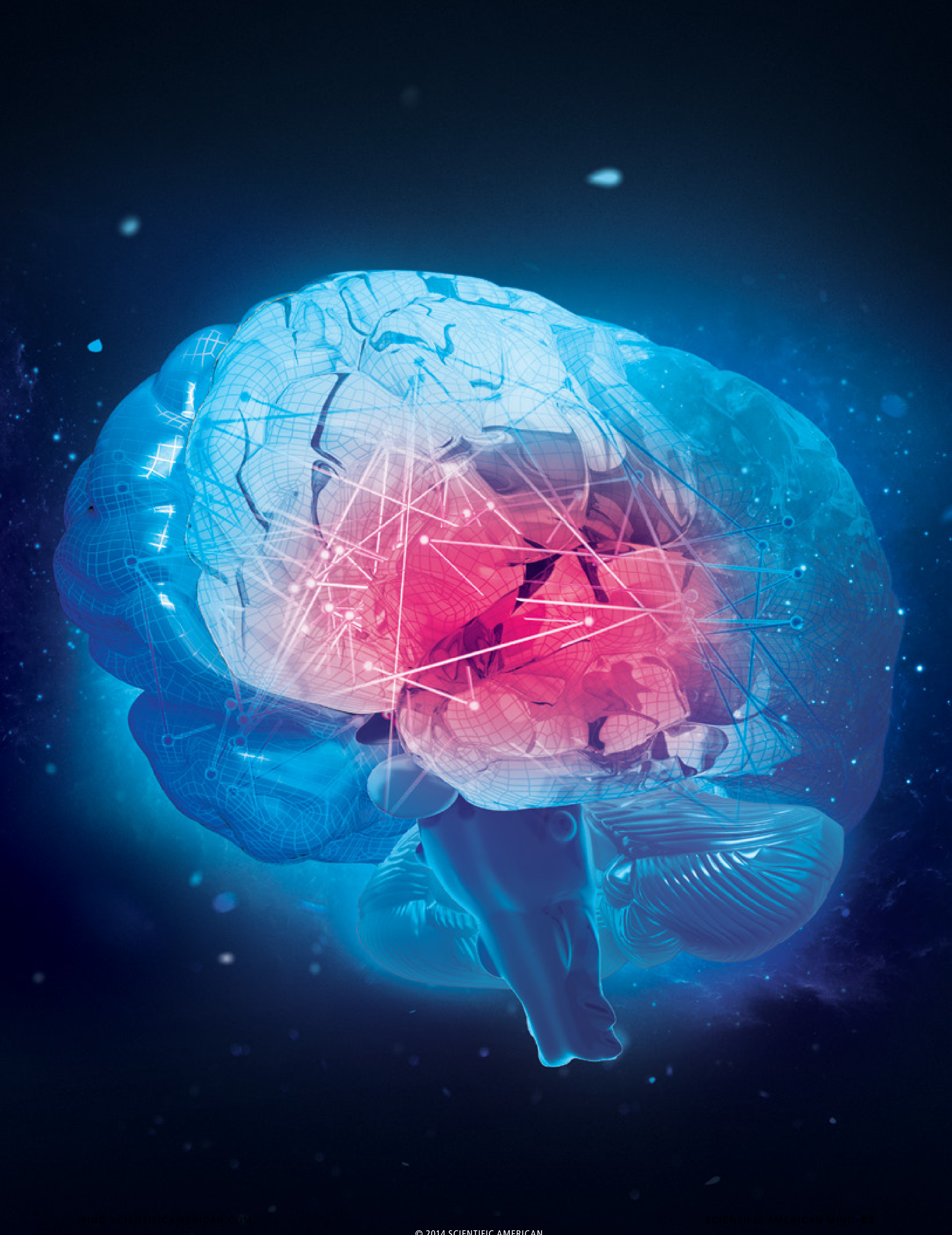
LET THERE BE LIGHT

By engineering brain cells to switch on or off in response to light, scientists are unlocking the mysteries of the mind and crafting new remedies for brain disorders

By Edward S. Boyden

Illustration by **VAULT 49**



In a neuroscience laboratory in Boston, a mouse explores a plastic box, poking its nose into this corner and that. The behavior is normal, but the rodent bears a novel prosthesis: a thin glass optical fiber extends from its head and connects to a laser that can generate brief pulses of blue light. The fiber is directed at a small cluster of cells deep in the brain that manufacture the neurotransmitter dopamine.

Drugs of abuse increase dopamine levels in the brain, suggesting that the neurotransmitter conveys reward or pleasure, sometimes to a detrimental end—but no one knows the precise role of dopamine-making cells in addiction. By stimulating these cells specifically, my group, working with neuroscientist Chris Fiorillo of the Korea Advanced Institute of Science and Technology, hoped to find out.

Perhaps out of curiosity, the mouse pokes its nose into a corner of the box equipped with a movement sensor, triggering a flash of blue light from the laser, which courses down the fiber and activates the dopamine neurons near its tip. The mouse pauses for a second and then jabs its nose again into the sensor, earning another pulse of light. Over and over, it repeats this behavior, working for light. The results, published in 2012, show that activating just this small cluster of dopamine cells, even briefly, can make an animal do more of what it was just doing. In this way, dopamine neurons could directly drive a pattern of behavior reminiscent of addiction.

Of course, dopamine cells are not normally activated by light. We make them light-sensitive using a technology we developed known as optogenetics. We endow neurons with molecules that act as miniature solar panels, which enable them to convert illumination into electrical signals, the currency of computation in the brain. By issuing these tiny solar panels to one type of neuron of the many thousands in the brain, we can determine the precise role of those cells in behavior, sensory processing or even disease.

For a century neuroscientists have used electricity to trigger neuronal activity, sending current down a conducting wire. In the 1950s neurosurgeon Wilder Penfield, for example, found that stimulating certain sites in the brains of epileptic patients could cause them to recall childhood memories. Others have found they could create visual perceptions, make ordinary things seem funny or even partially arouse people from a coma. Stimulating the brain can prove that neurons in a specific region drive complex emergent behaviors in a way that simply observing the brain cannot.

But because the brain packs approximately 100,000 neurons and a billion synaptic connections in every cubic millimeter of tissue, electrically stimulating even a tiny location in the brain will excite a very large number of intermeshed cells of different kinds. Thus, electricity cannot elucidate exactly which cells drive what behaviors. In contrast, if cells of a single type, such as dopamine neurons, are equipped with light-sensitive molecules, illumination will excite those cells exclusively. Over the past decade hundreds of research groups have used optogenetics to learn how various networks of neurons contribute to behavior, perception and cognition. For example, they have identified one set of neurons that triggers aggression, another that can drive memory recall and a third that can augment perception of detail. In recent years we have expanded our molecular toolbox to include not only molecules that enliven neurons but also those that silence them. We have found proteins that respond to different wavelengths of light, allowing scientists to modulate multiple sets of interacting neurons at once. The result is ever more precise manipulation of brain circuits.

Optogenetics is also revealing potential targets for the treatment of brain disorders, which affect more than a billion people worldwide. By revealing how neural circuits work, the technology could point to better targets in the brain for both drugs and

FAST FACTS
SOLAR-POWERED THOUGHT

1. Using optogenetics, scientists endow neurons with molecules that act as miniature solar panels, enabling the cells to convert illumination into electrical signals, the currency of computation in the brain.
2. By delivering the tiny solar panels to a single type of neuron of the many thousands in the brain, researchers can use light to determine the precise role of those neurons in behavior, sensory processing or even disease.
3. Over the past decade hundreds of research groups have used optogenetics to identify, among other things, a set of neurons in mice that triggers aggression, another that can drive memory recall and a third that can augment perception of visual details.

With my training in electrical engineering and physics, I hoped to develop tools to analyze the brain as if it were a computer circuit.

implanted electrical stimulators. If optogenetics could be adapted to humans, a process that would require advanced gene therapy techniques and is likely years away, brain dynamics could be sculpted with extreme precision. One might be able to instantly turn down the aberrant activity during an epileptic seizure or enhance motor function in patients with Parkinson's disease. Making visual cells responsive to light might even yield a treatment for blindness.

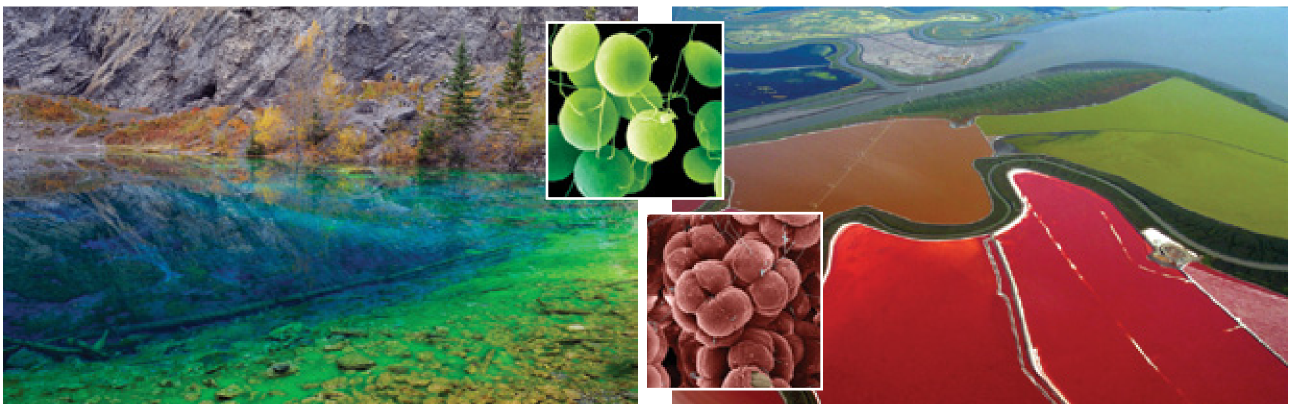
Adoptions from Algae

Organisms scattered all over the tree of life contain molecules that capture light and use it to drive important electrical or chemical processes. In photosynthesis, these molecules translate light into energy-rich chemical compounds; other life-forms engage these molecules in a primitive kind of vision. In 1971 the late biologist Walther Stoeckenius of the University of California, San Francisco, and biologist Dieter Oesterhelt, now at the Max Planck Institute of Biochemistry in Martinsried, Germany, discovered that a class of single-celled organisms that live in very salty water are endowed with light-driven proteins that sit in cell membranes. On illumination, the proteins transport protons (positively charged ions) from one side of the membrane to the other. These proteins, known as bacteriorhodopsins, support cellular metabolism and may help bacteria thrive in harsh environments where energy sources other than light are scarce.

In the late 1970s scientists identified light-driven chloride pumps known as halorhodopsins in the same organisms. And in 2002 a third class of molecules, light-gated ion channels known as channelrhodopsins, were discovered in green algae; they convert light into molecular signals that control the algae's flagella so that the microbes can steer toward the surface of ponds to capture sunlight. For decades biophysicists, microbiologists and other scientists studied these molecules to better understand how organisms interact with light.

As an engineer, I became fascinated with the potential utility of these tiny light-driven actuators. In the spring of 2000, as a graduate student at Stanford University, I was brainstorming with my fellow student Karl Deisseroth about technologies we could develop to radically accelerate the study of the brain. With my training in electrical engineering and physics, I hoped to develop tools to analyze the brain as if it were a computer circuit. I began to imagine inserting these microbial ion pumps into the membranes of brain cells so that shining a light on them would move negative ions into the cells to shut them down—or, potentially, to convey positive ions into the cells and boost their activity. Using either manipulation, we could determine the role of just those neurons in specific behaviors or pathological states.

The fact that living things made these proteins meant we could likely engineer them into other organisms, such as mice, and maybe someday into humans. In living creatures, genes specify the production of proteins, so if we delivered the genes for



To turn on or off specific neurons in the brain, scientists have borrowed light-sensitive proteins from microbes. One such protein comes from the green alga *Chlamydomonas* (*left inset*), whose habitats include freshwater lakes (*left*). Halobacteria (*right inset*), which produce several light-sensitive proteins, populate very salty water, including the salt ponds of San Francisco Bay (*right*).

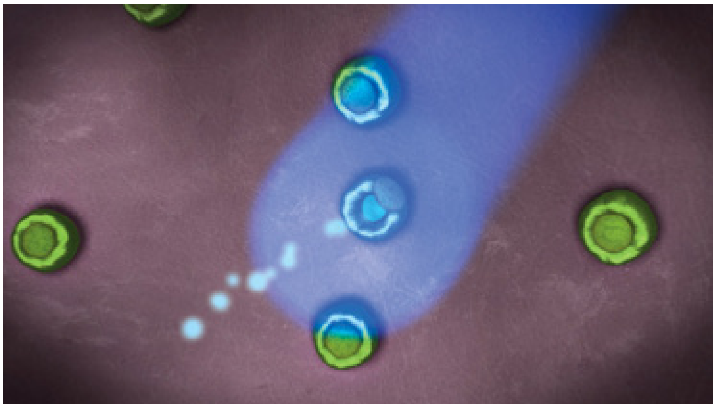
AGE FOTOSTOCK (*lake*); GETTY IMAGES (*salt ponds and green algae* Chlamydomonas); SCIENCE SOURCE (*halobacteria*) these light-sensitive proteins into brain cells, the cells could, in theory, do the rest. Current genetic engineering techniques do not allow us to systematically direct genes to specific cell types, such as dopamine neurons. We can, however, tailor a gene so that its protein is made, or expressed, only in certain cells. Because different types of cells turn on different sets of genes, we can take DNA sequences that only, say, dopamine neurons switch on and link those pieces to the gene we want to insert. Then when we deliver the gene to a mouse, only the dopamine cells will produce its protein.

I asked several colleagues to send me pieces of DNA encoding light-activated ion pumps so that I could start trying to get them into neurons. One challenge was finding light-driven pumps that would function in the mammalian brain, which is quite different from an extreme saltwater environment. In late 2003 I read a paper published earlier that year by biophysicist Georg Nagel of the University of Würzburg in Germany and his colleagues. Nagel's team had successfully inserted the gene for a light-gated ion channel from a green alga into cultured mammalian cells. The cells produced a functional protein, channelrhodopsin-2, that transported positively charged ions into the cells in response to light.

Deisseroth, then a postdoctoral scholar, and I asked Nagel to send us his gene. Deisseroth bathed cultured neurons with the gene, and at 1 A.M. on August 4, 2004, I exposed the first neuron to flashes of blue light from a lamp on a microscope. The experiment was a bit of a long shot. We had no idea whether an ion channel that evolved to help algae move toward light would have any effect on neurons. The channel might, for example, open at the wrong speed or generate too little current to alter neuronal signaling. The inserted protein could also prove toxic to the neuron for any number of reasons.

To my amazement, however, the first test neuron responded, firing electrical pulses just like those that neurons naturally generate. What is more, the neuron looked none the worse for wear. It easily survived the insertion of this protein adopted from a plant. We had used light to reliably stimulate electrical activity and neurotransmitter release in cultured neurons; we described these results in a 2005 paper.

I then began working with colleagues to expand our neural control toolbox. In a paper published in 2007 while I was an assistant professor at the Massachusetts Institute of Technology, neuroengineer Xue Han, now at Boston University, and I showed that on insertion into neurons, a halorhodopsin would pump in chloride ions (which are negatively charged) and silence neural signaling. In the next two years neuroengineer Brian Chow, now at the University of Pennsylvania, Han and I found light-driven proton pumps that could suppress neural activity by pumping positively charged ions out of cells in response to light.



Some algae have an eyespot (*left*) that enables them to swim toward light. When light hits the eyespot, protein channels open to let charged particles into it (*right*). This flow of charge fuels molecular motors that power the alga's whiplike flagella, which propel it.

COURTESY OF BOYDEN LAB

THE AUTHOR

EDWARD S. BOYDEN is an associate professor of biological engineering and brain and cognitive sciences at the M.I.T. Media Lab and the McGovern Institute for Brain Research at M.I.T. He recently shared the Grete Lundbeck European Brain Research Prize, the largest brain research prize in the world, for his work in optogenetics. He is interested in radically improving the human condition through new technologies for mapping and fixing the brain.

A few years ago our then graduate student Nathan Klapoetke discovered, through mining a database of gene sequences from algae, light-driven ion channels that can respond rapidly enough to produce the fastest electrical pulses seen in the brain. Also from this database, Klapoetke identified ion channels that activate neurons in response to red light, whose longer wavelengths can penetrate deeper into tissue than blue light can and thus can activate neurons from farther away. A graduate student in our lab, Amy Chuong, also found an ion pump that can silence neurons in response to red light, even deep in the brain. Together these molecules opened the door to turning up or down the volume on multiple populations of neurons using different colors of light, enabling scientists to draw sophisticated connections between various brain circuits and behavior. For instance, activating dopamine neurons while stimulating a sensory pathway might show us how patterns of activity from sensory neurons—such as those associated with drug-related objects or odors—drive behavior.

When scientists delivered light through the fiber, activating these neurons, the mice immediately attacked other mice. They also assaulted objects such as gloves.

Attack Neurons

We have distributed our newfound tools to well over 1,000 research groups worldwide. Using these microbial machines to control neurons, researchers are identifying the neural networks that drive particular behaviors. A few years ago neuroscientists Dayu Lin, now at New York University, and David J. Anderson of the California Institute of Technology wanted to know which cells in the brain could trigger violence. In work published in 2011 they and their colleagues searched for a molecular sign of recent neural activity in the brains of mice that had just been in a fight. They found this sign in a cluster of cells in the hypothalamus, a small, deeply embedded brain region. The activation of these neurons during aggressive behavior, however, did not mean they contribute to violence, because their activity could have been a by-product of computations elsewhere in the brain. So the researchers injected a virus carrying the gene for channelrhodopsin-2 into this part of the hypothalamus, where they also implanted an optical fiber. When they delivered light through the fiber, activating these neurons, the mice immediately attacked other mice. They even assaulted inanimate objects such as gloves, underscoring the cells' powerful influence over this complex behavior. Defining such circuits may lead us to an improved understanding of the causes of aggression and suggest new ways to help people control their actions.

Researchers have also used optogenetics to hunt down the neural basis of memory recall. In a 2012 study neuroscientists Xu Liu and Susumu Tonegawa, both at M.I.T., and their colleagues created transgenic mice that carried the gene for channelrhodopsin-2 but would only express the protein in neurons that had recently been active. The mice then heard a tone before receiving a shock. Over time the mice learned to associate the tone with the shock, and they froze from fear whenever they heard it. After a mouse learned this link, the researchers found that neurons in its dentate gyrus, a part of the hippocampus known to be involved in memory formation, were expressing channelrhodopsin-2, suggesting that these neurons were involved in creating the fearful memories. Delivering light to this region reactivated the neurons, and the animals would freeze again even in the absence of a tone, showing that these neurons can independently trigger the recall of specific memories. In this way, optogenetics can reveal how complex information is stored in the brain.

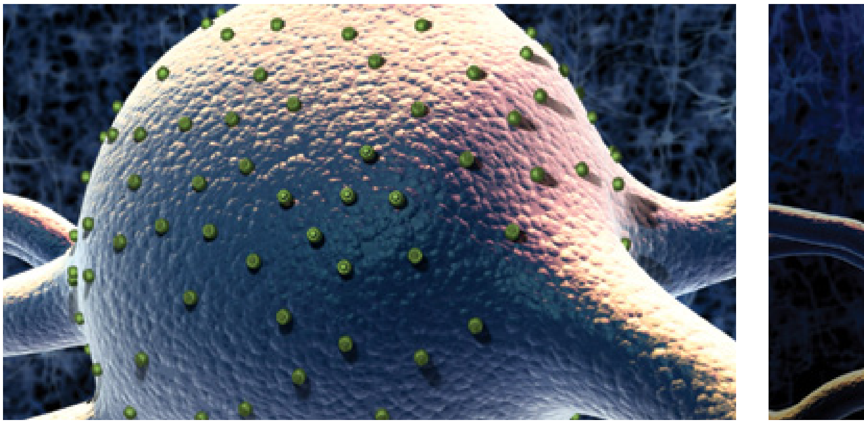
Optogenetic tools can also help scientists better understand the function of specific types of neurons within known brain circuits. In a study published in 2012 neuroscientists Seung-Hee Lee, now at the Korea Advanced Institute of Science and Technology, Yang Dan of the University of California, Berkeley, and their colleagues engineered mice to express optogenetic activators in star-shaped neurons in the visual cortex, at the back of the brain. When they flipped the light switch, selectively activating these neurons, the mice more reliably licked a spout when the scientists showed them an array of lines that signaled the availability of water from the spout. Activating these star-shaped neurons seemed to help the mice distinguish arrays of different orientations, perhaps sharpening their vision. As a result, they were more confident when the stimulus that signified the availability of water was present. The results indicate that this set of neurons can enhance the brain's ability to discriminate visual features in the environment.

Making a Move

These technologies can also be used to identify—and potentially target—specific circuits in the brain that underlie various neurological disorders. Patients with temporal lobe epilepsy (one of the most common types in adults) who do not respond to medication sometimes opt for surgical removal of the part of the brain generating the seizures. Depending on which tissue is removed, the treatment can cause permanent impairment in critical functions, such as speech or movement. The ability to reset the aberrant neural circuits with light could represent a safer option for these patients. In work published in 2013 neuroscientists Esther Krook-Magnuson and Ivan Soltesz and their colleagues at the University of California, Irvine, took a step in this direction in mice. These mice had been given a drug that made them prone to epileptic seizures but were also engineered with an antidote: they expressed the gene for a halorhodopsin in excitatory neurons in the forebrain. The scientists found that shining light on these cells as soon as a seizure began could, in many cases, halt the seizure within seconds.

In other cases, results from optogenetics experiments in animals have suggested safer ways of delivering existing treatments. For example, tens of thousands of patients with Parkinson's and other movement disorders have had electrodes implanted in their brains to facilitate movement and reduce tremors. The stimulation is often aimed at a deep-seated structure called the subthalamic nucleus because surgeons have serendipitously found that electrodes in that location have therapeutic effects. In an experiment published in 2009 Viviana Gradinaru, now a neuroscientist at Caltech, Deisseroth and their colleagues tested a less intrusive Parkinson's therapy in mice using optogenetics. Because of the influence of a drug, these mice were hobbled on one side of the body by a slow gait, among other characteristics of Parkinson's, causing them to walk in circles. When the researchers used light to activate certain cells in the motor cortex that made channelrhodopsin-2, the gait of these mice straightened out and their movements became more symmetrical. Because the motor cortex is on the brain's surface, this finding suggests that Parkinson's patients might benefit from electrodes placed more superficially in the brain or even outside on the scalp.

In another application of optogenetics, making visual cells responsive to light might one day become a remedy for some types of blindness. In the disorder retinitis pigmentosa, photoreceptor (light-sensitive) cells in the eye atrophy or die off as the result of any of more than 100 mutations in various genes, leading to blindness. Without photoreceptor



Scientists use genetic engineering techniques to insert copies of a light-sensitive ion channel from a microbe into the membrane of a neuron (*left*). When blue light shines on the neuron, the channels open; positive ions flow into the cell, activating it (*center*). At the far right, orange illumination silences a set of neurons engineered to carry light-sensitive ion pumps that admit negative ions.

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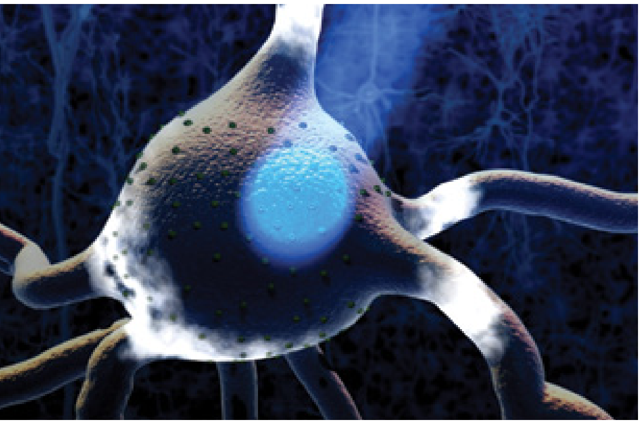
In another application of optogenetics, making visual cells responsive to light might one day become a remedy for some types of blindness.

cells, the eye cannot convert light into neural signals that the brain can interpret. Various research teams are exploring whether electrical stimulators connected to a camera can convey visual information from the captured image to spared visual cells. Because electricity spreads, however, this technique produces only low-resolution vision: people see points of light or heavily pixelated images. An alternative strategy is to genetically deliver one of the proteins that converts light into neural signals to a set of surviving cells. Such a technique has restored some vision in blind mice. Several teams, some of them at biotech companies, are now exploring whether this genetic modification could be a cure for blindness in people.



Engineering the Human Brain?

To use optogenetics to treat patients, however, would require several significant advances. By precisely manipulating the DNA of mice and other creatures very early in their development, we can insert a new protein into specific cells of their bodies. In humans, in contrast, making cells responsive to light would require inserting a new gene into a fully formed individual, and gene therapy techniques that can accomplish that feat cannot reliably restrict the expression of that gene to a specific cell type. Such a therapy—including the new, foreign proteins—would also have to be proved safe over the long term. In addition, we would need to develop implantable optical devices that could illuminate neurons over an extended period.

In the meantime, and perhaps more important, optogenetic tools will help us greatly refine our maps of the brain, which will then point the way toward strategies for fixing it. To make the most progress in this endeavor, we need to invent new ways of recording neural activity that show us how perturbation of a defined set of cells influences brain dynamics. In a step in this direction, we worked with physicist and neuroscientist Alipasha Vaziri of the University of Vienna in Austria and his colleagues earlier this year to develop a microscope optimized for imaging neural activity, in 3-D, throughout entire organisms.

The Obama administration's BRAIN Initiative, launched in 2013, is aimed at stimulating the development of technologies for revealing how the brain works. The discoveries in optogenetics underscore the importance of looking in unlikely places for those tools, from desert salt lakes to mountain ponds. The extraordinary story that began with curiosity about microbial proteins that had no obvious practical use is leading, half a century later, to the unraveling of such fundamental brain processes as thought and emotion and to the discovery of safer, more effective treatments for brain disorders. **M**

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TROUBLED TEENS

Kid Gloves for Young Offenders?

Research reveals that get-tough tactics may worsen rates of juvenile delinquency

Mike S. (not his real name) was 13 years old when one of us (Lilienfeld) met him on an inpatient psychiatric ward, where Lilienfeld was a clinical psychology intern. Mike was articulate and charming, and he radiated warmth. Yet this initial impression belied a disturbing truth. For several years Mike had been in serious trouble at school for lying, cheating and assaulting classmates. He was verbally abusive toward his biological mother, who lived alone with him. Mike tortured and even killed cats and bragged about experiencing no guilt over these actions. He was finally brought to the hospital in the mid-1980s, after he was caught trying to con railroad workers into giving him dynamite, which he intended to use to blow up his school. According to psychiatry's standard guidebook, the *Diagnostic and Statistical Manual of Mental Disorders* (now in its fifth edition), Mike's diagnosis was conduct disorder, a condition marked by a pattern of antisocial and perhaps criminal behavior emerging in childhood or adolescence.

Psychologists have long struggled with how to treat adolescents with conduct disorder, or juvenile delinquency, as the condition is sometimes called when it comes to the attention of the courts. Given that the annual number of juvenile court cases is about 1.2 million, these efforts are of great societal importance. One set of approaches involves "getting tough" with delinquents by exposing them to strict discipline and attempting to shock them out of future crime. These efforts are popular, in part because they quench the public's understandable thirst for law and order. Yet scientific studies indicate that these interventions are ineffective and can even backfire. Better ways to turn around troubled teens involve teaching them how to engage in positive behaviors rather than punishing them for negative ones.

You're in the Army Now

One get-tough technique is boot camp, or "shock incarceration," a solution for troubled teens introduced in the 1980s. Modeled after military boot camps, these programs are typically supervised by a drill instructor and last from three to six months. They emphasize strict rules and swift punishments (such as repeated push-ups) for disobedience, along with a regimen of physical work and demanding exercise. According to the National Institute of Justice, 11 states operated such programs in 2009. Indeed, Mike S. was sent to a boot camp program following his discharge from the hospital.

Even so, research has yielded at best mixed support for boot camps. In a 2010 review of 69 controlled studies, criminologists Benjamin Meade and Benjamin Steiner, both then at the University of South Carolina, revealed that such programs produced little or no overall im-

BY SCOTT O. LILIENFELD AND HAL ARKOWITZ

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Send suggestions for column topics to ***editors@SciAmMind.com***

ISTOCKPHOTO (*juvenile*); SEAN McCABE (*Lilienfeld and Arkowitz*) provement in offender recidivism. For reasons that are unclear, some of them reduced rates of delinquency, but others led to higher rates. Boot camps that incorporated psychological treatments, such as substance abuse counseling or psychotherapy, seemed somewhat more effective than those that did not offer such therapies, although the number of studies was too small to draw firm conclusions.

TEENS MUST LEARN ENDURING TOOLS—INCLUDING BETTER SOCIAL SKILLS—THAT **HELP THEM AVOID FUTURE AGGRESSION.**

Another method is "Scared Straight," which became popular following an Academy Award–winning documentary (*Scared Straight!*), which was filmed in a New Jersey state prison in 1978. Typically these programs bring delinquents and other high-risk teens into prisons to interact with adult inmates, who talk bluntly about the harsh realities of life behind bars. Making adolescents keenly aware of prison life is supposed to deter them from criminal careers. Yet the research on these interventions is not encouraging. In a 2003 meta-analysis (quantitative review) of nine controlled studies of Scared Straight programs, criminal justice researcher Anthony Petrosino, now at the research agency WestEd, and his colleagues showed that these treatments backfired, boosting the odds of offending by 60 to 70 percent.

The verdict for other get-tough interventions, such as juvenile transfer laws, which allow teens who commit especially heinous offenses to be tried as adults, is no more promising. In a 2010 summary, psychologist Richard Redding of Chapman University found higher recidivism rates among transferred adolescent offenders than among nontransferred ones.

Perils of Punishment

Psychologists do not know for sure why get-tough treatments are ineffective and potentially harmful, but the psychological literature holds several clues. First, researchers have long found that punishment-based strategies tend to be less effective than reward-based strategies for lasting behavioral change, in part because they teach people what not to do but not what to do. Second, studies indicate that highly confrontational therapeutic approaches are rarely effective in the long term. For example, in a 1993 controlled trial psychologist William Miller of the University of New Mexico and his colleagues found that counselors who used confrontational styles with problem drinkers—for example, by taking them to task for minimizing the extent of their drinking problem—had significantly less success in helping their clients overcome their addictions than did counselors who used supportive styles that relied on empathy. Similarly, a 2010 review by criminal justice researcher Paul Klenowski of Clarion University and his collaborators found that delinquency programs that involved confrontational tactics, such as berating children for misbehavior, were less effective than programs that did not use them.

What is more, adolescents with conduct disorder often enter treatment angry and alienated, harboring feelings of resentment toward authority. Get-tough programs may fuel these emotions, boosting teens' propensity to rebel against parents and teachers. Finally, some programs may inadvertently provide adolescents with role models for bad behavior. For example, some of the at-risk teens exposed to prisoners in Scared Straight programs may perceive them as cool and worth emulating.

These results show that merely imposing harsh discipline on young offenders or frightening them is unlikely to help them refrain from problematic behavior. Instead teens must learn enduring tools—including better social skills, ways to communicate with parents and peers, and anger management techniques—that help them avoid future aggression. Several effective interventions do just that, including cognitive-behavior therapy, a method intended to change maladaptive thinking patterns and behaviors, and multisystemic therapy, in which parents, schools and communities develop programs to reinforce positive behaviors. Another well-supported method, aimed at improving behavior in at-risk children younger than eight years, is parent-child interaction therapy. Parents are coached by therapists in real time to respond to a child's behavior in ways that strengthen the parent-child bond and provide incentives for cooperation [see "Behave!" by Ingrid Wickelgren; Scientific American Mind, March/April 2014].

The negative data on get-tough programs remind us that we should be wary of our subjective impressions of strategies that simply seem right or that we feel ought to work. Although we lost track of Mike S., we now know that a concerted effort to teach him more adaptive behaviors would have been more likely to put him on a productive path than would any attempt to scare him straight. **M**

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POCKET THERAPY

Mobile apps help you manage your mental health

Should your smartphone be your therapist? Thousands of mobile apps claim to help people improve their mental health. Some offer relationship advice and productivity tips; others aim to make psychiatric disorders easier to manage. Yet the vast majority of them have no solid scientific basis, as a recent study concluded. Last year the U.S. Food and Drug Administration announced that it would begin regulating medical apps that claim to diagnose various conditions, such as heart disease and sleep apnea. Psychiatric apps that serve to identify symptoms, rather than diagnose disease, may be exempt from oversight because the agency believes they pose a lower risk to the public.

Some experts, however, feel that psychiatric apps deserve the same scrutiny as medical devices and have raised concerns over their safety and effectiveness [see "Apps to Avoid," on opposite page]. Only more rigorous studies can ensure that these programs offer a real benefit, determine how they might complement other forms of therapy and help people make more informed decisions about which ones to use. Here SCIENTIFIC AMERICAN MIND takes a critical look at a range of popular mental health apps. —*Roni Jacobson*

DEPRESSION AND ANXIETY

Optimism
For iPhone/iPad
(*free*)

Optimism is a mood-tracking app for people with depression and bipolar disorder, as well as those simply looking to brighten their days. Users regularly record their emotional state, along with other factors, including the amount of caffeine or alcohol they have consumed each day and the quantity and quality of their sleep and exercise. The app charts these variables in a line graph, helping people visualize how various factors may interact to influence their mood. The app also allows users to record potential "triggers," or occurrences that negatively affect their mental health. By constantly keeping tabs on their mood and environment, users may learn to recognize key triggers and head off bouts of depression or anxiety before they occur. Although published data are lacking, psychologists at George Washington University are assessing the app's effectiveness in an ongoing study.

PTSD Coach
For iPhone/iPad and Android (*free*)

PTSD Coach was developed by the U.S. Department of Veterans Affairs with service members in mind, but it can be used by anyone dealing with trauma and anxiety. It is designed to supplement regular therapy for individuals coping with trauma and to help users track their symptoms. The app offers advice and coping strategies, such as relaxation techniques. When users indicate that they are in crisis, the app helps them find immediate support by directing them to the phone numbers of loved ones, as well as nearby treatment programs and hotlines.

Mobilyze!
For Android (*free but currently unavailable*)

This app from researchers at Northwestern University takes full advantage of users' smartphones to sense when they are depressed. It uses a phone's built-in accelerometer and GPS to collect data on a person's location and movement, and its algorithms monitor how often a user talks on the phone, texts and interacts with social media. When the app detects a pattern of isolation, it sends a text message or automated phone call urging the user to get out and do something fun. In a small pilot study, eight people with depressive disorders revealed significant improvements in their symptoms via self-reports and telephone interviews with the researchers. Yet the app had trouble accurately predicting users' moods, and the study itself was flawed because it failed to include a control group.

The team at Northwestern recently pulled the app off the market to refine its features. The researchers are currently recruiting volunteers for a larger trial on depression. The app will be rereleased in 2015, and those interested in testing the app can sign up at the developers' Web site at http://cbits.northwestern.edu/#!/page_participate

SuperBetter
For iPhone/iPad
(*$4.99*)

SuperBetter helps you work toward specific goals—such as reducing anxiety, losing weight or fighting depression—by allowing you to create your own superhero identity and adventure. The idea is that "gamifying" your goals may make it easier to achieve them and to stay motivated. To work toward a desired objective, you can develop your own adventure or choose from "Power Packs" of predefined quests, bad guys (that is, people or triggers that may trip you up along the way) and other activities developed with input from researchers at Stanford University, the University of California, Berkeley, and elsewhere.

In the "Lazy Exercise" Power Pack, for example, an activity could be dancing to your favorite song, and bad guys might include sitting for more than an hour at a time and driving when you could walk. You can also recruit "Allies"—friends from Facebook or other SuperBetter users—to play with you. In a small, unpublished randomized controlled trial in collaboration with the University of Pennsylvania, 19 people with self-reported depression improved by 17 points on a standardized depression test after six weeks of playing SuperBetter compared with about six points for those who did not play the game.

RELATIONSHIPS

Gottman Apps
For iPhone/iPad
(*$1.99 each*)

Married clinical psychologists John and Julie Schwartz Gottman developed 11 apps based on their own relationship research (John Gottman is also an emeritus psychology professor at the University of Washington) and have experience in counseling couples in family therapy. One, called Love Maps, is a relationship app designed to foster open communication between long-term partners. Another, called Open-Ended Questions, suggests conversation starters that couples can use to escape the monotony of everyday topics such as "What's for dinner?" Other apps help couples express their relationship needs in a positive, nonjudgmental light. Research shows that open communication, even about day-to-day minutiae, is associated with greater relationship satisfaction and lower divorce rates in couples who attend counseling. Though heavy on science, the apps' simple design may turn off more tech-savvy users. Text in the apps is displayed in a basic font on plain, Microsoft Paint–style backgrounds, and the software has limited functionality. One customer review notes that the app is basically "index cards with questions."

MEDITATION

Headspace
For iPhone/iPad and Android (*$95.88/year for full content*)

Headspace is a popular guided-meditation app that helps users achieve mindfulness, or a nonjudgmental, focused awareness of one's current emotional state. After a couple of minutes of breathing exercises, the app prompts users to pay attention to the sounds around them and to do a mental scan of their body for any aches and pains. Each session lasts 10 minutes and is led by app developer Andy Puddicombe, a former Buddhist monk. The theory behind mindfulness is that when practitioners notice these details, they become more in tune with their moods and can more easily identify and control their emotions in any situation. In fact, research shows that practicing mindfulness can relieve stress, reduce anger and help people overcome addiction.

BRAIN TRAINING

Lumosity
For iPhone/iPad
(*free*)

Like Candy Crush but better: Lumosity offers fun games aimed at building users' brainpower. Players can choose from more than 40 games focusing on different skills, including attention, memory, processing speed and problem solving. Pilot studies led by Stanford University researchers indicated that Lumosity enhanced memory, multitasking ability and processing speed in children and adults with cancer-related brain injuries. Yet when several independent research groups tried to replicate these promising results in healthy individuals, they failed. Although participants in these latter studies became more proficient in performing the in-game tasks over time, the improvements did not enhance cognitive ability in real life. Lumosity may provide some short-term benefits, but do not expect monumental transformations.

Mind Games
For iPhone/iPad, Android and Windows (*free*)

The 28 games included in this app are aimed at people who want to sharpen their wits while juggling a busy schedule. Each game targets a specific skill set and takes only two to three minutes to play. Some games involve memory and concentration; others are more traditionally academic, such as those for building vocabulary or freshening up math skills. In a game aptly entitled Face Memory, users are challenged to improve their facial recall so they will never again find themselves awkwardly asking an acquaintance, "What's your name again?" Although the app has not been tested in a controlled study, Mind Games is based on psychology research that demonstrates that people who alternate between different cognitive exercises learn more efficiently.

PRODUCTIVITY

30/30
For iPhone/iPad
(*free*)

People prone to distraction may benefit from 30/30, a time management app that helps users focus on the task at hand. The app first prompts users to set up to-do lists for the day and estimate how long each item will take to complete. When users are ready to start tackling the list, they can tap on a countdown timer, kicking off a 30-minute work session during which they have committed to focusing on one task at a time without interruption—absolutely no e-mail, Facebook, Twitter, *Big Bang Theory* recaps or any other microdistractions. When the time is up, users get a 30-minute break (or less) before the cycle starts again. (Users, however, are not obligated to work in 30-minute chunks; they can set any length of time to complete a task.) 30/30 is based on research indicating that separating work into smaller chunks makes it more manageable, with frequent breaks serving as rewards for staying on track.

MEDICATION MANAGEMENT

MediSafe
For iPhone/iPad and Android (*free*)

MediSafe is a "virtual pillbox" that can help keep track of complex medication schedules. The app reminds users when to take each medication and prompts them to scan the bar code on the prescription label once they have done so. If a person forgets or misses a pill, MediSafe sends a notification to a designated friend or relative, who can check in on the patient. Data accumulated over eight weeks in 2012 indicated that 81 percent of MediSafe users were taking their medication on time. By comparison, World Health Organization data suggest that the average rate of medication adherence is 50 percent. MediSafe also sends users reminders to refill their prescriptions when they are getting low.

Apps to Avoid

Watch out! Some apps make big claims with little evidence

According to the FDA, those psychiatric apps that provide coping techniques for people with diagnosed mental health conditions pose low risks to consumers. These apps will be regulated at the FDA's discretion, and many will therefore escape the agency's safety and effectiveness assessments. Some experts, however, say that these apps can still be hazardous if they give out shoddy advice or otherwise mislead vulnerable consumers. "Some of [these apps] are really good, and some of them are awful," says Michael Van Ameringen, a psychiatry professor at McMaster University in Ontario. "Clinicians and consumers need help sorting through them."

For instance, be wary of apps designed by software companies that fail to include insight from a medical professional (such as many of the hypnosis apps out there), as well as apps claiming to use audio tones to induce certain mental states, such as decreased anxiety (there is no scientific validity to these claims).

The Anxiety and Depression Association of America, of which Van Ameringen is a board member, is currently developing a rating system to screen out bad apps. Here are some things to keep in mind when browsing mental health apps:

- If you are in immediate distress, see a doctor. Apps cannot replace diagnosis and treatment; they are supplements only.
- Read the terms of use. Confidentiality is an important concern for many people dealing with mental health issues. Make sure you know what the app's developers are doing with your data.
- Check out the science. Many apps claim to have experimental support, but often those studies are performed by teams of in-house researchers and lack scientific rigor. Studies conducted by independent researchers and published in peer-reviewed journals provide a more objective assessment.
- Take design into account, too. You are more likely to use the app regularly if the experience is easy and enjoyable. It also helps if the app can be customized to your unique needs, Van Ameringen says.

ISTOCKPHOTO (*warning sign*)

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

Why do we want to bite cute things, like adorable newborn babies?

—Emma Poltrack, Virginia

Gwen Dewar, biological anthropologist and founder of the Web site Parenting Science, responds:

The urge to nibble cute creatures might be a case of getting one's wires crossed. In a recent study, researchers performed functional magnetic resonance imaging scans on women who unwittingly sniffed newborn infants. The odors activated reward-related areas of the brain, the same regions that trigger a pleasurable rush of dopamine when we get our hands on a desirable bit of food. A similar neural effect was reported in an earlier study where women viewed images of babies.

This research suggests that, to some degree, our brains respond in a parallel way when perceiving cuteness and seeking food, and perhaps our psychological experience of wanting to bite arises from that physiological overlap. Yet we may have other reasons to associate babies and biting. A kind of friendly "social biting" may be part of our evolutionary heritage.

Creatures throughout the primate world are often drawn to their species' offspring. Some Old World monkeys, for instance, will line up for the chance to handle another monkey's new baby, and nuzzling—rubbing one's nose and mouth against the baby—is one of the most common forms of handling.

None of this is real biting. When biting occurs, animals get hurt. Yet pseudo-biting, if you will, is prevalent, especially in the form of the teasing nips that mammals give one another during rough-and-tumble play. The reasons for this behavior are not entirely clear. When a puppy gently bites your hand, is he honing his motor skills? Rehearsing for real-life combat? Engaging in a friendly game?

All those explanations are possibilities, but what is interesting here is that play-biting generally happens between trusted allies. Primatologist Susan Perry in the anthropology department at the University of California, Los Angeles, and her colleagues have seen capuchin monkeys bite one another in careful, seemingly ritualistic ways, clamping down on fingers hard enough to trap them but apparently causing no pain. The researchers think the monkeys may be testing their social bonds, sending the message, "I'm so trustworthy, you can stick your finger in my mouth."

So biting is not only for feeding or aggression. Behaviors that resemble biting—mouthing, nuzzling and gentle nips—seem to be a normal part of the friendly social repertoires of many mammals. Also, of course all mammals begin life as enthusiastic social nibblers, extracting milk from their mother's mammary glands by chomping down with their toothless jaws. Against this background, the impulse to gobble up an adorable baby does not seem so bizarre. It may be one more example of friendly, pseudo-biting—and a sign of good intentions.

Brain size has increased for most of our existence, so why has it started to diminish for the past few thousand years?

—via e-mail

Christopher Stringer, a paleoanthropologist and research leader on human origins at the Natural History Museum in London, replies:

Indeed, skeletal evidence from every inhabited continent suggests that our brains have become smaller in the past 10,000 to 20,000 years. How can we account for this seemingly scary statistic?

Some of the shrinkage is very likely related to the decline in humans' average body size during the past 10,000 years. Brain size is scaled to body size because a larger body requires a larger nervous system to service it. As bodies became smaller, so did brains. A smaller body also suggests a smaller pelvic size in females, so selection would have favored the delivery of smaller-headed babies.

What explains our shrinking body size, though? This decline is possibly related to warmer conditions on the earth in the 10,000 years after the last ice age ended. Colder conditions favor bulkier bodies because they conserve heat better. As we have acclimated to warmer temperatures, the way we live has also generally become less physically demanding, which overall serves to drive down body weights.

Another likely reason for this decline is that brains are energetically expensive and will not be maintained at larger sizes unless it is necessary. The fact that we increasingly store and process information externally—in books, computers and online—means that many of us can probably get by with smaller brains. Some anthropologists have also proposed that larger brains may be less efficient at certain tasks, such as rapid computation, because of longer connection pathways.

The way we live may have affected brain size. For instance, domesticated animals have smaller brains than their wild counterparts probably because they do not require the extra brainpower that could help them evade predators or hunt for food. Similarly, humans have become more domesticated. But as long as we keep our brains fit for our particular lifestyles, there should be no reason to fear for the collective intelligence of our species. M

JAMIE CARROLL *iStockphoto*

1 SENTENCE SNAKE

A statement about someone's smarts is coiled in the grid below. To spell it out, start with an "H" and move to an adjacent letter in any direction. Two letters will not be used; all others will be used exactly once. (Hint: the enumeration is 2'1, 3, 3, 9, 5, 5, 2, 3, 5.)

X	N	O	H	E	S	N	O
K	T	T	H	E	H	T	T
C	H	G	I	B	R	I	G
O	E	L	R	O	S	E	H
L	B	H	C	P	T	T	X

2 CONFOUNDING COMPOUNDING

Place the same four-letter word in each blank below to make four common words.

_______ RAY

_______ END

_______ AGE

_______ ICO

3 SCRAMBLE

Mix the letters in the box below with another unspecified letter to create two common nine-letter English words.

P	D	A
E	?	R
R	E	I

4 WORD WHEELS

Spell an eight-letter word in each box by beginning with the correct letter and moving clockwise or counterclockwise around the box, using each letter only once. The question mark represents a letter that you must supply, which is the same for both words.

E	?	T
U		S
S	E	L

C	O	A
S		L
E	?	F

5 HOMOPHONES

Use the clues to fill in each pair of blanks below with words that are pronounced the same but have different meanings and different spellings.

a) Part _______ **Tranquility** _______

b) Movement of the sea _______ **Put together with a cord or rope** _______

c) Sardonic _______ **A grain** _______

6 SIBLING SUM

Suzanne has three times as many brothers as she has sisters, but her brother James has the same number of sisters as brothers. How many boys and girls total are in the family?

7 ANAGRAMS

For each pair, think of the five-letter answer to the clue on the top, then add a "P" to the letters and rearrange them to make the six-letter answer to the clue on the bottom.

a) Say "#@&%*!!!!" _______
Evergreen tree _______

b) Dutch flower _______
Preacher's place _______

c) The briny _______
Chicago gangster Al _______

d) Quarrel _______
Czech city _______

8 BALANCED BUDGET

Ryan is going to have a barbecue at his house. He spends half of what he has plus $5 for steak. He spends half of what is left plus $5 on fruits for a salad, half of what is left plus $2 for paper plates and the remaining $3 on ice cream. How much money did he start with?

9 MINI CROSSWORD

Across
1. "Amazing!"
4. Eye part
6. Man
7. Wild blue yonder

Down
1. False locks
2. Mine yards
3. Flirtatious gesture
5. Pig's digs

1	2	3	■
4			5
6			
■	7		

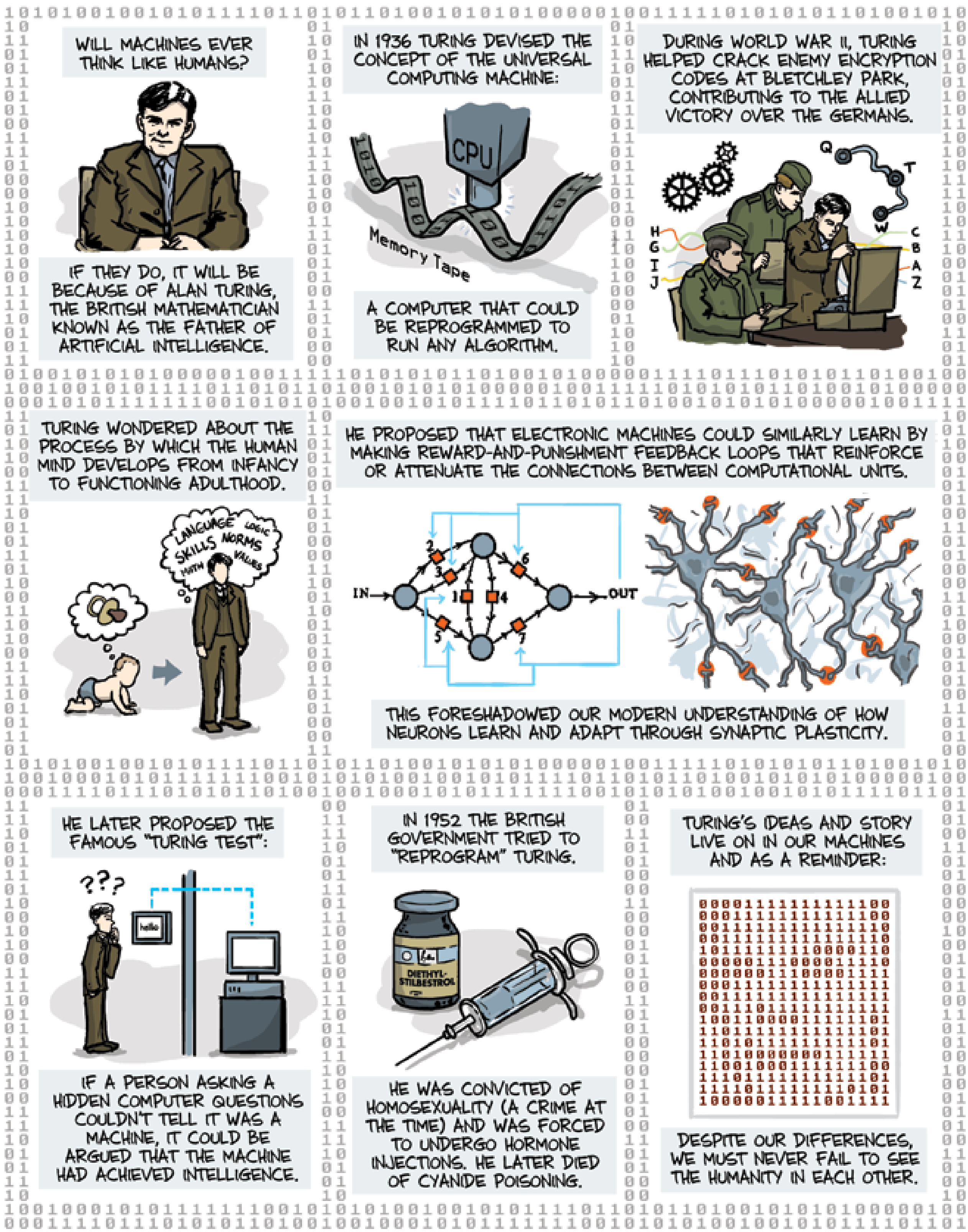
Answers

1. HE'S NOT THE BRIGHTEST PORCH LIGHT ON THE BLOCK.
2. PORT (PORTRAY, PORTEND, PORTAGE, PORTICO).
3. DRAPERIES and DESPAIRER. The missing letter is "S."
4. The missing letter is "R." STREUSEL, ALFRESCO.
5. a) PIECE, PEACE, b) TIDE, TIED, c) WRY, RYE.
6. Two girls and three boys.
7. a) CURSE, SPRUCE, b) TULIP, PULPIT, c) OCEAN, CAPONE, d) ARGUE, PRAGUE.
8. $70.
9.

W	O	W	■
I	R	I	S
G	E	N	T
■	S	K	Y

TURING'S TEST

BY DWAYNE GODWIN & JORGE CHAM



Dwayne Godwin is a neuroscientist at the Wake Forest University School of Medicine.
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