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WITH COVERAGE FROM nature

FROM THE EDITOR

Liz Tormes

Astonishing Conscious Mind

Human consciousness remains one of the biggest puzzles in science. Indeed, we have made moderate progress on how to measure it but less on how it arises in the first place. And what gives rise to our sense of self? In February we published a special collector's edition exploring these mysteries and more. This issue's cover story, by researcher Robert Martone, is a fascinating look at new discoveries on a region of the brain that helps us create a mental picture of our present and future identities (see "How Our Brain Preserves Our Sense of Self").

Elsewhere in this issue, contributing editor Daisy Yuhas talks with linguist Sarah Frances Phillips about new research illuminating the neurological basis for multilingualism (see "How Brains Seamlessly Switch between Languages"). How the brain both creates our individual reality and enables us to thrive in that reality is nothing short of astonishing.

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On the Cover

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WHAT'S INSIDE

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NEWS

Cannabis Use in Pregnancy Is Linked to Child Anxiety, Hyperactivity

Changes in the activity of immune system genes in the placenta could explain the association, researchers speculate

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As with most decision points around pregnancy, cannabis use is a fraught subject. Researchers can't assess it in randomized trials because dosing pregnant people with the psychoactive substance is unethical. The next best thing is studies with enough participants who use cannabis on their own, allowing for comparisons with those who do not.

The findings of one such study, published on November 15, 2021, in the *Proceedings of the National Academy of Sciences USA,* highlight symptoms of increased anxiety, hyperactivity and aggression in children whose parents used cannabis during pregnancy. And its analysis of placental tissue points to changes in the activity of immunity-related genes.

Today pregnant people "are being bombarded with a lot of ads to treat nausea and anxiety during pregnancy" with cannabis, says the paper's senior author Yasmin Hurd, director of the Addiction Institute of Mount Sinai. "Our studies are about empowering them with knowledge and education so that they can make decisions."

The results are "very striking, very much a first," says Daniele Piomelli, a professor and director of the

Center for the Study of Cannabis at the University of California, Irvine, who was not involved in the work. Pregnancy studies in rodents and even in sheep, which have a placenta more like ours, have required cautious interpretations of findings that show effects on offspring behavior and function, he says. The new study is one of the first to tackle the question in people "in a systematic way," Piomelli adds.

Hurd and her colleagues worked with 322 parent-child pairs, beginning with profiles of genetic activity in placental samples taken at birth. When the children reached about three years of age, samples of their hair were tested for levels of stress hormones. From ages three to six, they also underwent recordings of their heart-rate variability, another indicator of stress response, and evaluations for anxiety, aggression and hyperactivity. The researchers used statistical methods to exclude effects from cigarette smoking, parental anxiety and other factors that could confuse associations with cannabis use.

In the placental tissues, gene activity was altered with cannabis exposure during pregnancy: genes related to the inflammatory response showed decreased function. Anxiety and hyperactivity levels were higher in children from cannabis-exposed pregnancies and were associated with the placental gene patterns. The researchers speculate that a decline in the activity of immune-related genes in the placenta might explain the behavioral findings.

> **"We always have to interpret human studies with a grain of salt."**
> ***—Daniele Piomelli***

"We always have to interpret human studies with a grain of salt," Piomelli says, because factors other than cannabis could still be the true cause of the behavioral outcomes, including experiences after birth. Although the researchers in this study "did a really good job" of controlling for these factors, he says, "there is only so much one can do."

Anxiety is an example of a potential confounding factor, says Mitch Earleywine, a professor of psychology at the University at Albany, State University of New York, who was not involved in the study. Anxiety has some genetic underpinning, which parents can pass to children. For this reason, he says, "I'm not sure that cannabis is really the issue" instead of genetics. Earleywine is also an advisory board member of the National Organization for the Reform of Marijuana Laws (NORML), which advocates for the legalization of cannabis.

Hurd agrees that human studies will always involve elements that can muddy the findings. "Yes, genetics plays a role, maternal anxiety plays a role, their postnatal environment plays a role," she says. But even with all of that, the associations her group found with cannabis are results that "I don't think we can ignore."

For parents who used cannabis during pregnancy and find these results potentially unsettling, "the human organism is very resilient," Piomelli says. "Appropriate care and love and attention to your kid can certainly reduce any potential harm." Hurd says that one strategy to reduce harm is to be alert to signs of anxiety or hyperactivity in children and get them help right away.

—Emily Willingham

Cells Deep in Your Brain Place Time Stamps on Memories

Researchers are unlocking not just the "what" and "where" of a recollection but also the "when"

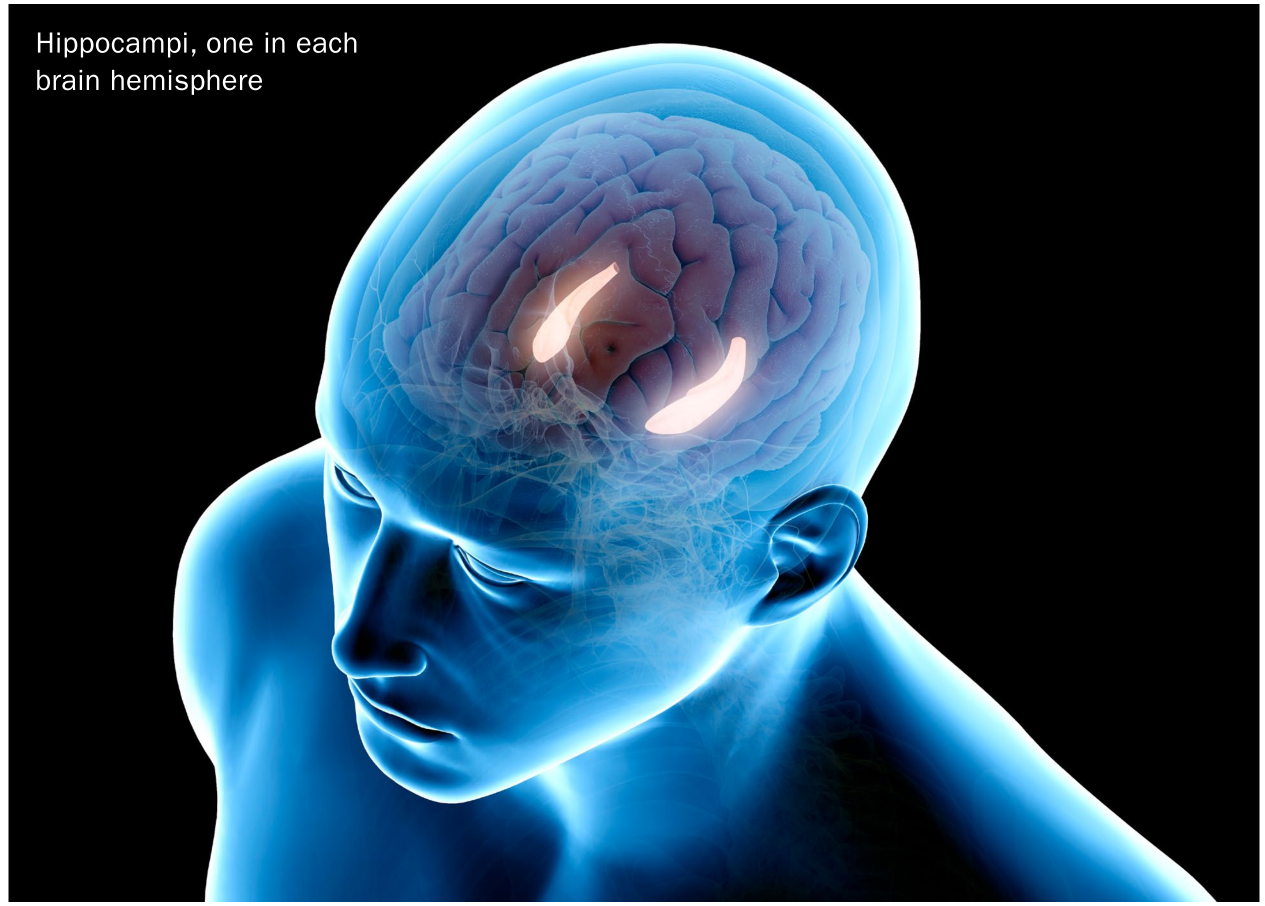
How does our brain know that "this" follows "that"? Two people meet, fall in love and live happily ever after—or sometimes not. The sequencing of events that takes place in our head—with one thing coming after another—may have something to do with so-called time cells recently discovered in the human hippocampus. The research provides evidence for how our brain knows the start and end of memories despite time gaps in the middle. As these studies continue, the work could lead to strategies for memory restoration or enhancement.

The research has focused on episodic memory, the ability to remember the "what, where and when" of a past experience, such as the recollection of what you did when you woke up today. It is part of an ongoing effort to identify how the organ creates such memories.

A team led by Leila Reddy, a neuroscience researcher at the French National Center for Scientific Research, sought to understand how human neurons in the hippocampus represent temporal information during a sequence of learning steps to demystify the functioning of time cells in the brain. In a study published last summer in the *Journal of Neuroscience,* Reddy and her colleagues found that to organize distinct moments of experience, human time cells fire at successive moments during each task.

The study provided further confirmation that time cells reside in the hippocampus, a key memory processing center. They switch on as events unfold, providing a record of the flow of time in an experience. "These neurons could play an important role in how memories are represented in the brain," Reddy says. "Understanding the mechanisms for encoding time and memory will be an important area of research."

Matthew Self, a co-author of the study and a senior researcher in the department of vision and cognition at the Netherlands Institute for Neuroscience, emphasizes the importance



Hippocampi, one in each brain hemisphere

Sebastian Kaulitzki/Science Photo Library/Getty Images

of these hippocampal time cells' role in encoding experiences into memory. "When we recall a memory, we are able to remember not only what happened to us but also where we were and when it happened to us," he says. "We think that time cells may be the underlying basis for encoding when something happened."

While researchers have known about the existence of time cells in rodent brains for decades, they were first identified in the human brain late last year by researchers at the University of Texas Southwestern Medical Center and their colleagues. To better understand these cells, Reddy and her team examined the hippocampal activity of patients with epilepsy who had electrodes implanted in their brain to evaluate a possible treatment for their condition. The subjects agreed to participate in two different experiments after their surgery.

"During the surgery, the electrodes are inserted through small holes of around two millimeters in the skull. These holes are sealed until the patients recover from the surgery and are monitored for up to two weeks with the electrodes in place in an epilepsy monitoring unit, or EMU," Self says. "We record the hippocampal neuronal activity while the patients are performing tasks in the EMU for a period of about one week after the surgery."

In the first experiment, the study participants were presented with a sequence of five to seven pictures of different people or scenes in a predetermined order that was repeated multiple times. A given image, say, of a flower, was shown for 1.5 seconds, followed by a half-second pause and then another image—a dog, for instance. In a random 20 percent of the image intervals throughout the sessions, the parade of pictures stopped, and participants had to decide which of two images was the next correct one in the sequence before continuing. The researchers discovered that over the course of 60 repetitions of the entire sequence, all of the time-sensitive neurons fired at specific moments in intervals between quizzes, no matter which image was shown.

A second experiment followed the same design, except that after the sequence was repeated for a fixed number of times, a black screen was shown for 10 seconds—a gap interval that was intended to act as a distraction. For half of the participants, these intervals occurred after every five repeats of the sequence (resulting in six gaps in the experiment). For the remaining participants, they occurred after every two repeats of the sequence (resulting in 15 gaps). The sequence was repeated only 30 times.

The participants in the second experiment were quizzed about the order of the images in the sequence while the electrical activity from individual cells in their brain was recorded. Some neurons fired at one moment, corresponding to a particular image. Others did so at another moment for a different image. Time cells corresponding to a specific image still switched on during the 10-second gaps in which no image was shown. These gaps appeared to help subjects remember more pictures and their correct order. During the gap periods, about 27 percent of the time cells were activated.

"We hope a clear understanding of the cellular contributions to memory functions will bring us closer to understanding why memory functions are lost in some diseases and how these diseases can be treated."
—Jørgen Sugar

To address the question of whether time information was present in the activity of hippocampal neurons, the researchers stimulated a subset of time cell neurons that were activated in response to an image. The firing activity of each neuron was modeled as a function of time, image identity, and whether the temporal period corresponded to an image or the interstimulus interval (ISI) periods—the 0.5-second gaps between the pictures.

The researchers could decode different moments in time based on the activity of the entire group of neurons—evidence that the human brain contains time-tracking neurons. "We think that the population of time cells in the hippocampus is representing several different and overlapping timescales," Self says. "The activity of these cells is present throughout the trial, providing a time stamp for an event." Yet the fact that these cells also represent the content of our memory (the "what" as well as the "when") makes things more complex, he explains. "We don't fully understand how the memory is encoded," Self says, "but the activity pattern across the hippocampus appears to simultaneously provide us with both the time stamp and the contents of the experience."

Self adds that this information may be combined with signals that indicate the context of the experience, but further research is needed to understand this mechanism. "It's no use encoding that you saw your friend at the beginning of an event without also encoding the context—that the event entailed 'walking around the supermarket,' " he says. "Our research aims to understand how time information is combined with contextual information to provide temporal structure to our memories."

The results seem to be similar to previous studies in rats demonstrating that time cells are the same as "concept cells" that respond to different representations of the same stimulus—that these cells encode both a concept and a time. "Time cells in [the] rat hippocampus are also place cells that respond when the rat is in a particular location," Self says. "It appears that hippocampal cells are multidimensional and can encode different aspects of our experiences in their firing patterns."

The paper answers a key question about human time cells, remarks Stefan Leutgeb, chair of the neurobiology section at the University of California, San Diego. "The current study makes a couple of important contributions. First, it provides further confirmation that time cells not only are common in the rodent hippocampus but also can be observed in high proportions in the human hippocampus," says Leutgeb, who was not involved with the work. "In fact, the proportion of time cells that were detected in humans in the present study is higher, compared with the previous study."

The findings might explain why some people with damage to their hippocampi—one of which resides in each brain hemisphere—can remember events but have trouble placing them in the right order—a problem for patients with Alzheimer's disease and other neurodegenerative conditions. "We hope a clear understanding of the cellular contributions to memory functions will bring us closer to understanding why memory functions are lost in some diseases and how these diseases can be treated," says Jørgen Sugar, an associate professor of physiology at University of Oslo, who was not involved in the new study.

Researchers in this field are looking forward to taking the work further. "The next step is to develop noninvasive or invasive methods of modulating the activity of time cells and time cell circuits," says Bradley Lega, an associate professor of neurological surgery at U.T. Southwestern Medical Center, who was senior author of the study that first documented the presence of time cells in the human brain last year. "This may provide a neuromodulation strategy for memory restoration or enhancement. The activity of time cells can also be monitored to determine what is occurring as electrical impulses are applied during such a procedure."

Some scientists think this work could assist in one day developing "memory prosthetics"—a technique that would allow a computer to insert or delete memories with electrodes placed in the brain. Such a step would raise ethical issues about the manipulation of memories, but it is probably not close to being realized.

That potential technology could also be used for treating post-traumatic stress disorder or Alzheimer's. "It could be tempting to develop such devices so that memories can be deleted or inserted, but I don't see how these devices could be regulated to prevent misuse [insertion of false memories or deletion of important memories]," Sugar says. "I think a more reasonable strategy is to focus our efforts on preventive treatments of memory disorders."

"I hope work in humans can reveal how time cells are actually contributing to encoding and recall of a unique one-shot memory," he adds. "Then the human race would be optimistic of the time when this emerging research will be put into use in helping us understand how our brain knows the start and end of memories despite time gaps between events."

—Abdulrahman Olagunju

This Protein Could Boost Brain Function without Exercise

An exercise pill might one day produce health gains without the exertional pain

The drumbeat of exercise's brain benefits may sound familiar. Most of us know that getting our move on can mean a boost to mental and neurological health. But what if, through understanding these biochemical processes, we could get all of that brain gain without going through the exercise pain? Mouse experiments have already demonstrated the feasibility of such a shortcut. And there is a hint that the results in rodents could work in humans as well.

When plasma from well-exercised mice is injected into their idling counterparts, the sedentary rodents have improved memory and reduced brain inflammation. The blood of Olympic athletes is not about to be transfused into the arms of sofa spuds—at least not yet. But people with mild cognitive impairment who exercise for six months show increases in a key protein identified in the "runner-mouse plasma." The same protein may be able to whisper its chemical message across the notoriously choosy blood-brain barrier and trigger anti-inflammatory processes in the brain.

These findings, published on December 8, 2021 in *Nature*, offer new details of how exercise benefits the brain and how molecules boosted by physical activity communicate across the organ's strict gatekeeper. The results also hint at a surprising role for the liver and anticlotting systems in these effects and possibly point the way to a futuristic scenario of exercise in a pill—or perhaps a plasma injection.

"Puzzle pieces are coming together," says Saul Villeda, an associate professor in the department of anatomy at the University of California, San Francisco, about these hints of multisystem involvement in exercise's effects on the brain. Villeda, who was not involved in the new study, and his colleagues previously identified a protein in exercised-mouse plasma that refreshed neurons in the aging mouse brain. "We're starting to identify factors in the blood that can target different facets of decline or pathology, and this one really highlights blood factors affecting inflammation in the brain," he says. "The word that keeps popping into my head is 'convergence.'"

On the path to convergence, behavioral scientist Zurine de Miguel, now an assistant professor at California State University, Monterey Bay, and her colleagues at Stanford University and the Veterans Affairs Palo Alto Health Care System first had to let mice exercise. The animals ran their heart out for 28 days, and then their plasma was transferred to mice that had not touched a running wheel during that time. The recipient animals showed improvements in learning and memory after they had received the runner plasma. Their brain, in turn, revved up genes that produced proteins that facilitated memory and learning and showed a dampened inflammatory response. When the researchers deliberately induced brain inflammation in the animals, the runner-mouse plasma dialed back that response, too.

Maridav/Alamy Stock Photo

The team next looked at what the runner plasma contained. They found increased levels of anticlotting proteins, including one called clusterin, which helps to clear cells of debris. Homing in on this protein, the investigators tested the effects of stripping it from the runner plasma. Brains of sedentary mice receiving clusterin-free plasma showed much less anti-inflammatory activity.

The team also found that clusterin readily attached to the cells that form the blood-brain barrier. When they mimicked the effects of physical activity by injecting the protein into the circulation of mice genetically modified to have neurodegenerative disease, the animals' brain inflammation also declined.

Finally, the researchers wanted to see if exercise causes clusterin elevations in people. They measured the protein in 20 veterans with mild cognitive impairment before and after six months of structure physical activity and found that the levels increased.

De Miguel notes that in her and her colleagues' study, results differed somewhat between male and female mice. Despite similar anticlotting protein profiles between the sexes, the females showed more variability.

The hormones they make can affect anticlotting factors, de Miguel says, and the possibility that some female mice were in a sexually receptive stage during the study might explain this greater variation.

The experiment illustrates a growing recognition of the brain's dependence on assistance from outside the neural no-fly zone. The liver and heart are the most likely sources of clusterin, the authors say. The results implicate both organs as sources of beneficial molecules resulting from physical exercise, de Miguel says. "They all seem to be cross talking to the brain," she adds.

Villeda says that his group's work with runner plasma in aging mice also implicates the liver. The organ produces an enzyme linked to cognitive improvements in the animals, and the same enzyme was also increased in the blood of older active people. The liver connection "was surprising to us because it wasn't usually what you focus on when you think about exercise," he says. With the liver connection, "these mechanisms are starting to converge and come into a similar space."

Although physical activity is closely linked to good health, it may be pos-sible to overdo exercise. There are hints that some people who engage often in highly strenuous physical activity may have increased risk for amyotrophic lateral sclerosis. "There is some information out there that says that too much exercise can impair some of your immune response and make you susceptible to opportunistic infections," de Miguel says.

How will runner plasma be used as a therapy if these effects in mice bear out in people? "I have more hope now than when I started my lab because it was difficult to think about identifying all of these factors," Villeda says. "But now we have candidates, and when you have those, you can start thinking about small-molecule development."

De Miguel says that a possible first step might be testing which exercise protocols trigger the biggest increases in proteins that carry a brain benefit. As with mice, someone in need of the brain-boosting power of physical exercise could simply receive an injection of runner plasma, getting a runner's gain without the ensuing pain.

—*Emily Willingham*

A Portable MRI Makes Imaging More Democratic

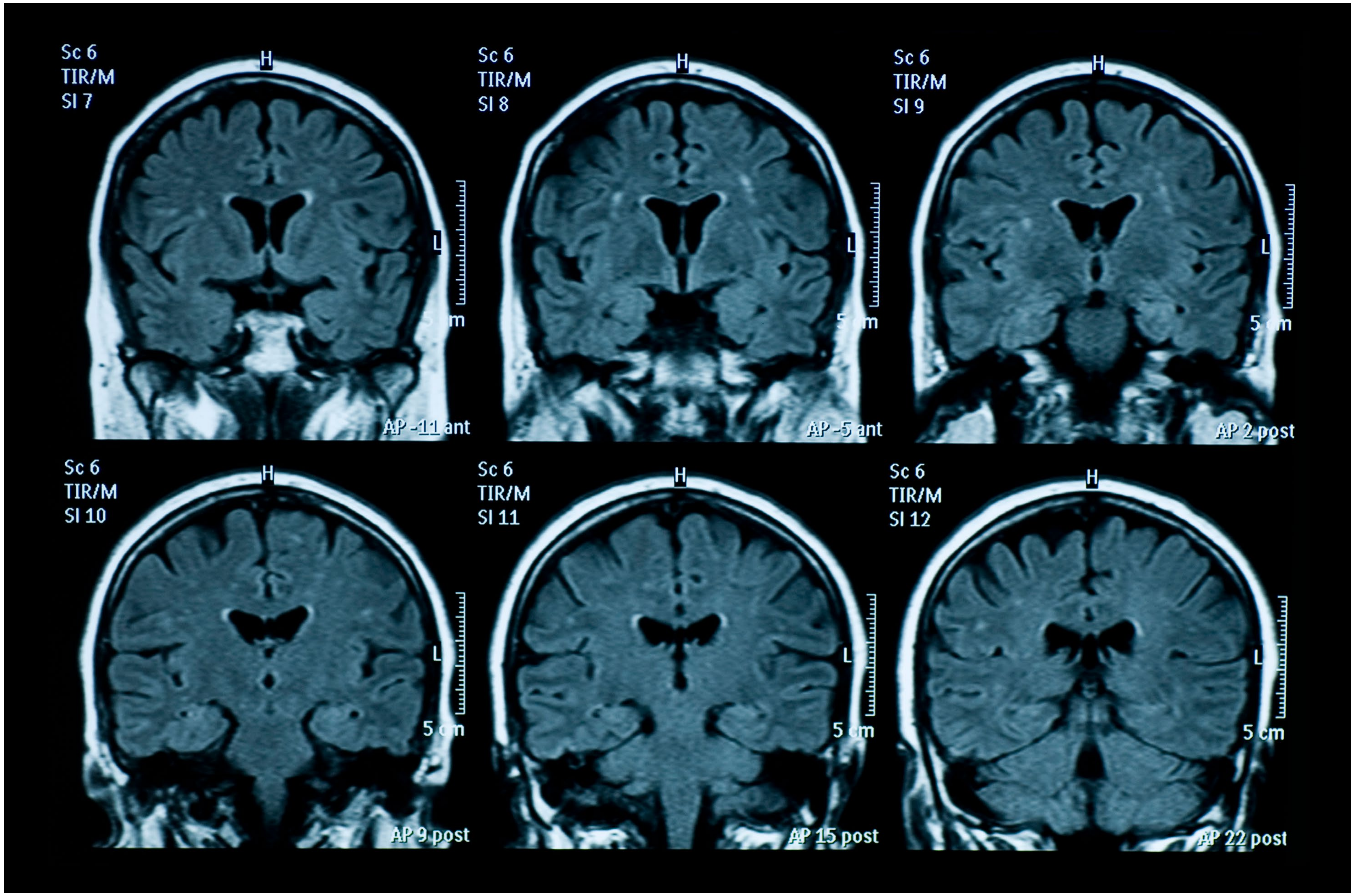
An open-source approach downsizes today's clunking behemoths with permanent magnets and deep-learning algorithms

Magnetic resonance imaging (MRI) scanners are the most valuable diagnostic tool we have for assessing brain injuries and disorders. Yet around two thirds of people worldwide do not have access to MRI technology, and more than 90 percent of the devices are located in high-income countries. Expense is the big reason: a typical MRI machine costs around $1 million to $3 million. They need a purpose-built room to shield the scanner from outside signals and to contain the powerful magnetic fields generated by their superconducting magnets, which require liquid-helium cooling systems that are pricey to run.

Low-cost, portable alternatives may soon start seeing widespread use. In a December 14, 2021, study in *Nature Communications,* researchers at the University of Hong Kong, led by biomedical engineer Ed Wu, describe an MRI scanner that needs no shielding and draws power from a standard wall socket. The approach, known as ultralow field (ULF) MRI, lacks the clarity and resolution required for precision diagnostics, but it is much less expensive, with material costs under $20,000, the study authors estimate. What's more, the machine's design and algorithms are open source, inviting researchers everywhere to help develop the technology.

MRI exploits the fact that we are mostly made of water. The protons in hydrogen atoms have magnetically charged "spins," which are aligned by the magnetic field and probed by radio-frequency pulses. Different tissues have distinct water concentrations and magnetic environments, and these differences appear as light and dark contrasts in reconstructed images.

Rather than using superconducting electromagnets, the ULF design employs permanent magnets, thereby eliminating the need for cooling. The permanent magnets generate only 0.055 tesla, so no magnetic shielding is needed (standard MRI scanners



Fine details in standard MRI images such as these currently elude ultralow field scanners, which instead may be useful in urgent cases where patients cannot be moved.

yumiyum/Getty Images

use 1.5- or 3-tesla fields). The main trade-off is that the signals are weaker, so signal-to-noise ratio is worse, and as a consequence, image resolution is lower.

To maintain portability, the ULF design eschews physical RF shielding. Instead the researchers used a "deep learning" algorithm trained to recognize and predict interference signals, which are then subtracted from the measured signals. "That's one very useful innovation here," says biomedical engineer Sairam Geethanath of Columbia University, who was not involved in the study. "It's similar to noise-cancellation headphones, where you're trying to learn the noise pattern in real-time and suppress it."

The team demonstrated the device by scanning 25 patients and comparing the images with those from a standard MRI machine. The researchers could identify most of the same pathologies, including stroke and tumors. "The images appear of sufficient quality to be clinically useful in a number of scenarios," says neuroscientist Tom Johnstone of Swinburne University of Technology in Melbourne, Australia, who was not involved in the study. "Rapid assessment of stroke, which has a large impact on success of interventions, could be facilitated by ULF MRI being located in more towns or even mobile units."

The new design joins a growing list of other ULF MRI scanners being developed. A company called Hyperfine, based in Guilford, Conn., received FDA approval last year for its portable scanner, but details of the design are proprietary. Wu and his colleagues have made their data, designs and code available online, which could speed ULF improvements and control costs. (Hyperfine's machine is more than twice the estimated price of the Hong Kong team's.)

Despite their promise, ULF devices are not intended to replace high-field scanners. They hold promise in "triage" settings, where patients cannot be moved or time is critical. "It has a role to play as an escalating device," Geethanath says. The range of applications will likely grow as performance improves, and Wu has some ideas about this. "Right now MRI systems are built as if we don't know anything about what we're scanning, but often the information we need is very subtle," Wu says—namely, to identify what's different. "That's going to be a huge revolution, driven by cheap computing."

He envisions broader use of MRI technology, more closely matched to clinical needs at point of care. "The nuclear magnetic resonance phenomenon is a gift from nature," he says. "We must use it more."

—*Simon Makin*

COVID Is Driving a Children's Mental Health Emergency

Deaths of parents and other terrible experiences have hurt hundreds of thousands, so new initiatives are trying to help families in pain

When COVID shut down life as usual in the spring of 2020, most physicians in the U.S. focused on the immediate physical dangers from the novel coronavirus. But soon pediatrician Nadine Burke Harris began thinking of COVID's longer-term emotional damage and those who would be especially vulnerable: children. "The pandemic is a massive stressor," explains Burke Harris, who is California's surgeon general. "Then you have kids at home from school, economic hardship, and folks not being able to socialize." These stresses could be particularly toxic for children, she and another state health official wrote to health providers in April 2020. In December 2021 U.S. Surgeon General Vivek Murthy issued a similar warning about children for the entire country.

The toxicity has become all too real after almost two years, driven by not just disarray but death as well. As of last June, more than 140,000 children lost a close caregiver—such as a parent—to COVID, according to research published in the journal *Pediatrics.* Since 2019 there has been a rise in suicide attempts among people younger than age 18, researchers at the Centers for Disease Control and Prevention found when they examined mental health–related emergency room visits during the past three years. And a study of pediatric insurance claims filed between January and November 2020, conducted by the nonprofit FAIR Health, found a sharp increase in mental health–related problems, especially generalized anxiety disorder, major depressive disorder and intentional self-harm. These and other distressing trends recently led the American Academy of Pediatrics and two other health organizations to declare that children's mental health is currently a national emergency.

Burke Harris says those patterns arise from what pediatric health specialists term adverse childhood experiences (ACEs). These events include 10 types of specific traumas that range from direct abuse and neglect to overall household dysfunction. The adverse experiences activate the brain's fight-or-flight system—a normal response to an immediate physical danger such as a bear rushing at you. But "what happens when the bear comes every night?" Burke Harris asks. Because adverse events put children in prolonged and repeated danger, it extends their stress response and creates damage.

When COVID disrupted the routine and resources that school and after-school care ordinarily provide, many children were left to face ongoing hazards at home, including parental issues such as intimate partner violence and substance misuse. Both of these problems significantly rose during the pandemic, according to researchers.

As the pandemic wore on, California, guided by Burke Harris's warnings, took some action to protect its children. Last October the state legislature passed the ACEs Equity Act, a first-in-the-nation law requiring insurance that covers preventive care and pediatric services to also cover in-depth screenings for adverse events. And, since January 2020, California's ACES Aware initiative has been educating clinicians about nonmedical interventions available to patients facing adverse events, and the state's Medicaid program has paid eligible providers $29 per screening. Such regular screenings—which involve asking intimate questions in a nonthreatening and supportive manner—are linked to a variety of positive health outcomes. A recent literature review found patients associate these screenings with greater trust in their doctors. And clinicians say the screenings help them identify social factors that influence health, which allows them to offer more effective care.

MoMo Productions/Getty Images

Lisa Gantz, a pediatrician at the Los Angeles County Department of Health Services, is one of more than 20,000 health providers in California who have received free two-hour online training offered in the state. By teaching her how to screen for and respond to adverse events, Gantz says the training has changed the way she approaches clinical care. She remembers one recent appointment with an underweight four-month-old and his mother. "We had gone through all of the feeding [methods], and I really wasn't able to come up with a reason why this child wasn't growing," Gantz says. But when she talked to the mother gently about possible changes at home, Gantz learned the child's parents had recently separated. And the family faced newfound financial hardship—a circumstance true of nearly half of U.S. households by August 2020, according to a national survey.

"As soon as the mom felt safe, we learned that the husband was deported, finances were tighter, and the mom needed to water down her son's formula to make ends meet," Gantz says. "She was too embarrassed to tell me that before, plus a mom's not going to walk in for a checkup and say, 'By the way, dad's not here anymore.' But the screenings create a space to have these larger conversations about what's going on at home." With that information, Gantz was able to connect the mother and her baby with a social worker and to public services that could help them pay for more formula.

Gantz describes the work of treating adverse experiences as creating a "medical neighborhood"—a cohesive unit that responds to the multifaceted nature of children's mental health with equally multifaceted resources.

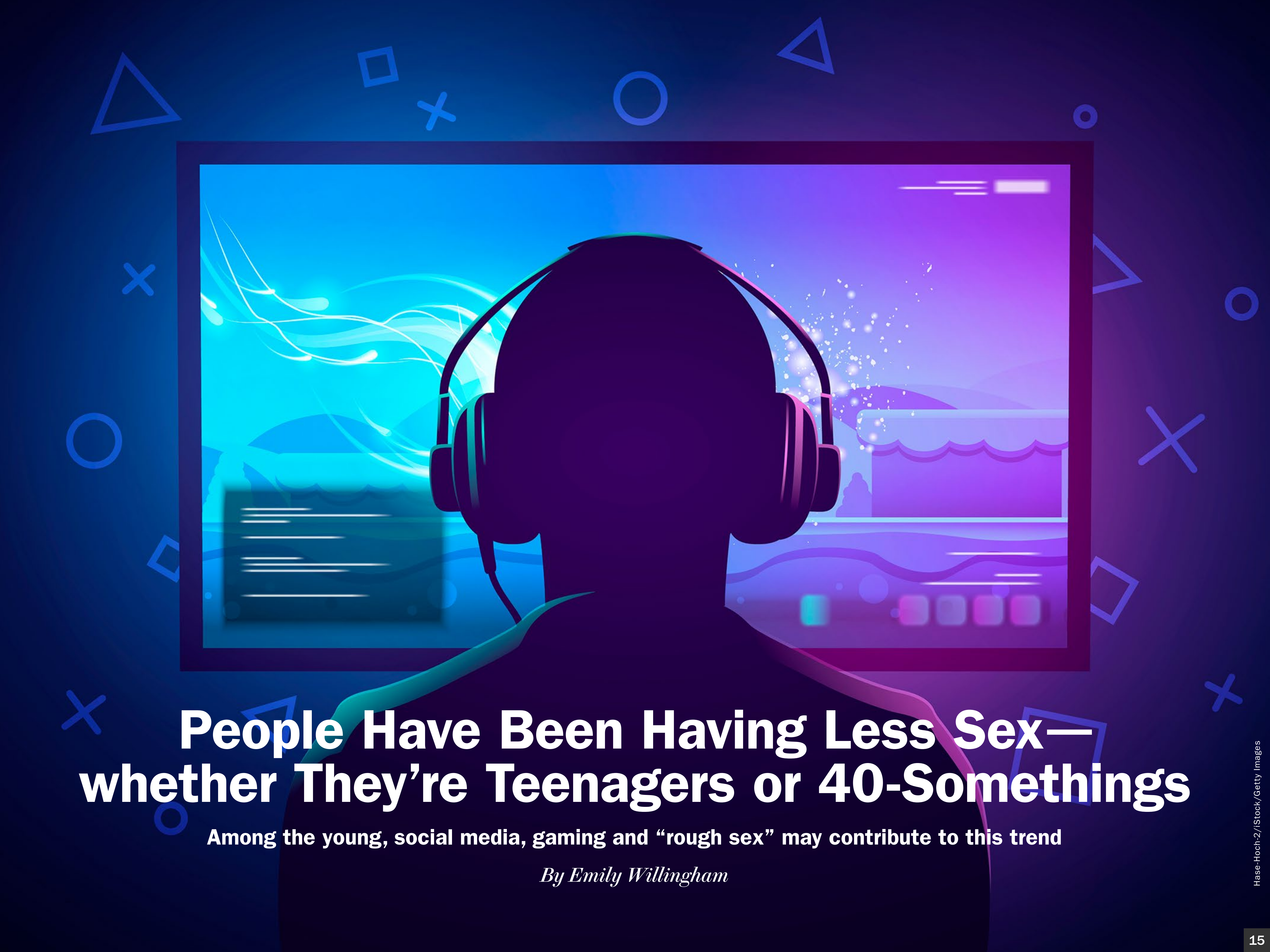
Efforts in other states are trying to reduce children's adversity by helping parents tackle their pandemic-related problems. In North Carolina, for example, the Raleigh-based nonprofit SAFEchild offers a Circle of Security Parenting (COSP) program. Small groups of parents in the program meet weekly to reflect on their behavior and improve their relationships with their children. Before teaching parents how to listen, the program first helps them feel heard.

That step is crucial if interventions are going to go beyond "telling people what to do" and actually create lasting change, says Ginger Espino, a COSP facilitator at SAFEchild. She notes that many parents in the groups are victims of adverse events in their own childhood. "It's about breaking that cycle of abuse and empowering parents to have confidence that they can meet any of their child's needs, even if those needs were not met during their own childhoods," Espino explains. By inviting participants to affirm their own strengths, talk about concerns, and construct what security looks and feels like within the safe support group, the program aims to help parents create that same loving, nurturing environment for children at home. "They realize, 'Oh, my child's not trying to drive me crazy. My child has a need, and I need to figure out how to meet that need,'" she says.

A few other states have recently introduced efforts to address the surge of pandemic-provoked adverse events. In May 2021 Maryland issued an executive order to create an ACE awareness day and announced a $25-million fund to expand the state's youth development programs to every county. And Wyoming is using California's approach to reimburse health providers for their ACE screenings of eligible Medicaid patients, says Elaine Chhean, who assists the executive director of the National Academy for State Health Policy, which co-published a paper on various ways that states try to prevent or mitigate adverse experiences.

Nationally, there have been a few moves to help deal with adverse events. Last May bipartisan congressional representatives from Georgia and Utah introduced a bill to expand ACE research and data collection. And that month the nonprofit ACE Resource Network launched an awareness campaign called Number Story. The program, so named because a clinical questionnaire about adverse events gives a person a score based on the number of such experiences, uses conversations with celebrities such as John Legend and Camila Cabello to educate the public about adverse events and how to recognize when they are going through one or more.

Sarah Marikos, executive director of the ACE Resource Network, says such recognition can help change behavior and motivate people to seek help. "In my grandparents' day, it was the norm to smoke, but now it's not. And that's the same thing we want to do around ACEs," she says. *—Julia Hotz*



People Have Been Having Less Sex—whether They’re Teenagers or 40-Somethings

Among the young, social media, gaming and “rough sex” may contribute to this trend

By Emily Willingham

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Emily Willingham is a science writer and author of *Phallacy: Life Lessons from the Animal Penis* (Avery, Penguin Publishing Group, 2020) and *The Tailored Brain: From Ketamine, to Keto, to Companionship: A User's Guide to Feeling Better and Thinking Smarter* (Basic Books, 2021).

Human sexual activity affects cognitive function, health, happiness and overall quality of life—and, yes, there is also the matter of reproduction. The huge range of benefits is one reason researchers have become alarmed at declines in sexual activity around the world, from Japan to Europe to Australia. A recent study evaluating what is happening in the U.S. has added to the pile of evidence, showing declines from 2009 to 2018 in all forms of partnered sexual activity, including penile-vaginal intercourse, anal sex and partnered masturbation. The findings show that adolescents report less solo masturbation as well.

The decreases "aren't trivial," as the authors wrote in the study, published on November 19, 2021, in *Archives of Sexual Behavior*. Between 2009 and 2018 the proportion of adolescents reporting no sexual activity, either alone or with partners, rose from 28.8 to 44.2 percent among young men and in 2009 from 49.5 to 74 percent among young women. The researchers obtained the self-reported information from the National Survey of Sexual Health and Behavior and used responses from 4,155 people in 2009 and 4,547 people in 2018. These respondents to the confidential survey ranged in age from 14 to 49 years.

The study itself did not probe the reasons for this trend. But *Scientific American* spoke with its first author Debby Herbenick, a professor at the Indiana University School of Public Health–Bloomington, and Tsung-chieh (Jane) Fu, a co-author of the paper and a research associate at the school, about underlying factors that might explain these changes. [*An edited transcript of the interview follows.*]

Given that research in other parts of the world has already indicated decreases in partnered sex, what do your recent findings add to the picture?

HERBENICK: Our study tracks the declines, too, and extends the research because Jane [Fu] and our larger team tracked sex behaviors in really detailed ways. We looked at penile-vaginal sex, partnered masturbation, and giving and receiving oral sex. We saw declines across all categories. And we included adolescents, too. The decline in adolescent masturbation is interesting, and we were the first to include it. That one deserves a lot more attention.

What might explain declines among young people?

FU: We need more studies to tell us why. But for young people, computer games, increasing social media use, video games—something is replacing that time. During that period from 2009 to 2018, different types of social media emerged. This is always evolving, especially for younger people.

HERBENICK: We don't expect there to be one explanation or one driver in these decreases. We fully expect that there are multiple things going on for different age groups, different partnership status, different genders. You don't need those individual pieces to explain a big part of a notable decrease, but … each one [might] explain a percentage point or two.

Is there any contribution from increases in people expressing an asexual identity?

HERBENICK: We don't know why more people are identifying as asexual, but I do think more people are aware of it as a valid identity. Even compared with when I started teaching human sexuality in 2003, I routinely had one student in my class who might identify as asexual. Now I have three or four. That's striking to me. I love that young people are aware of so many different ways to put into words how they feel about themselves. For many of them, they feel that it's okay to opt out of sex.

In your paper, you bring up increases in "rough sex" as potentially contributing to declines. Can you explain what you mean by rough sex, and how it could be playing a role in these changes?

HERBENICK: Especially for those 18 to 29 years old, there have been increases in what many people call rough sex behaviors. Limited research suggests that an earlier idea of this was what I would consider fairly vanilla rough sex: pulling hair, a little light spanking. What we see now in studies of thousands of randomly sampled college students is choking or strangling during sex. The behavior seems to be a majority behavior for college-age students. For many people, it's consensual and wanted and asked for, but it's also scary to many people, even if they learn to enjoy it or want it. It's a major line of research for our team: to understand how they feel, what the health risks are and how that fits into the larger sexual landscapes.

FU: We have seen what seem to be real shifts in those behaviors. We don't know to what extent that may be driving some people to opt out, but we do know that some people are feeling frightened and don't know what to make of what's being presented to them, especially young adults. They could consent to sex, but something like choking might happen without them being asked before. We see a lot of gender effects in a lot of behaviors for different nonheterosexual identities. For example, bisexual women experience a lot more of these aggressive behaviors.

HERBENICK: We have really been trying to untangle that, too, because it's not clear from our research how much of those elevated rates are wanted and pleasurable or unwanted, because bisexual women also report higher rates of sexual victimization.

In the report, you note that there are probably multiple reasons that people's sexual expression has changed.

HERBENICK: Various studies around the world have proposed different explanations, such as economic status. Lower income is associated with greater declines. One study looked at use of computer games among young people [as a possible explanation]. Some folks have tracked declines in alcohol use, and we know that [alcohol use] can be associated with disinhibition. We have seen, somewhat, [an] increase in sex toy use—from what we looked at, not a massive increase. If there is a change, it's probably just going to contribute to one of the blips. I don't expect it to be the explanation.

Do you have suggestions for people who might be reading this interview and wondering, "Should I do something with this information right now?"—maybe from the perspective of themselves, their partner or partners, or discussions with their children?

FU: For parents, it would be great to have open conversations with their children, especially teens, about sex. Sex in recent years looks very different, whether it's the emergence of technologies or of new sexual behaviors. We hope that parents can play an active role in guiding their children, not just to warn them of the risk of various sexual behaviors but also to educate them on how to have meaningful relationships and eventually satisfying and pleasurable sex.

HERBENICK: For many of us, I think it is worth asking a few things: How do I feel about my sexual life? How does my partner feel? Ask them! Some people may look around and feel like the sexual interactions they do have are pleasurable, connecting, joyful and make up a satisfying sex life for them. Others might look around and say, "You know, 10 to 15 years ago, when we couldn't stream as many fun shows on TV, we watched a lot less television, and we had sex more often. I wonder how we might have sex more often?"

More generally, could you elaborate a bit about how sexual activity with or without partners intersects with other aspects of health and what "sexual health" looks like?

HERBENICK: Sexuality is such an important part of life, and understanding changes that occur matters to how we understand what is shifting about the human experience. We know that sexual activity can help people to relax, fall asleep, reduce stress, feel intimate and connected, and thereby improve their relationships—and may even help to boost their immune system. And sex can also just be fun, pleasurable and joyful—a way to express oneself in vulnerable ways. Sexual health is multidimensional and not just about the presence or absence of infections or disease but about the potential for pleasure, access to accurate information about sexuality, bodily autonomy, and ability to have sexual experiences that are free from violence or coercion.

What sorts of effects on these behaviors do you already see or anticipate from the pandemic, which of course was not tracked in your study?

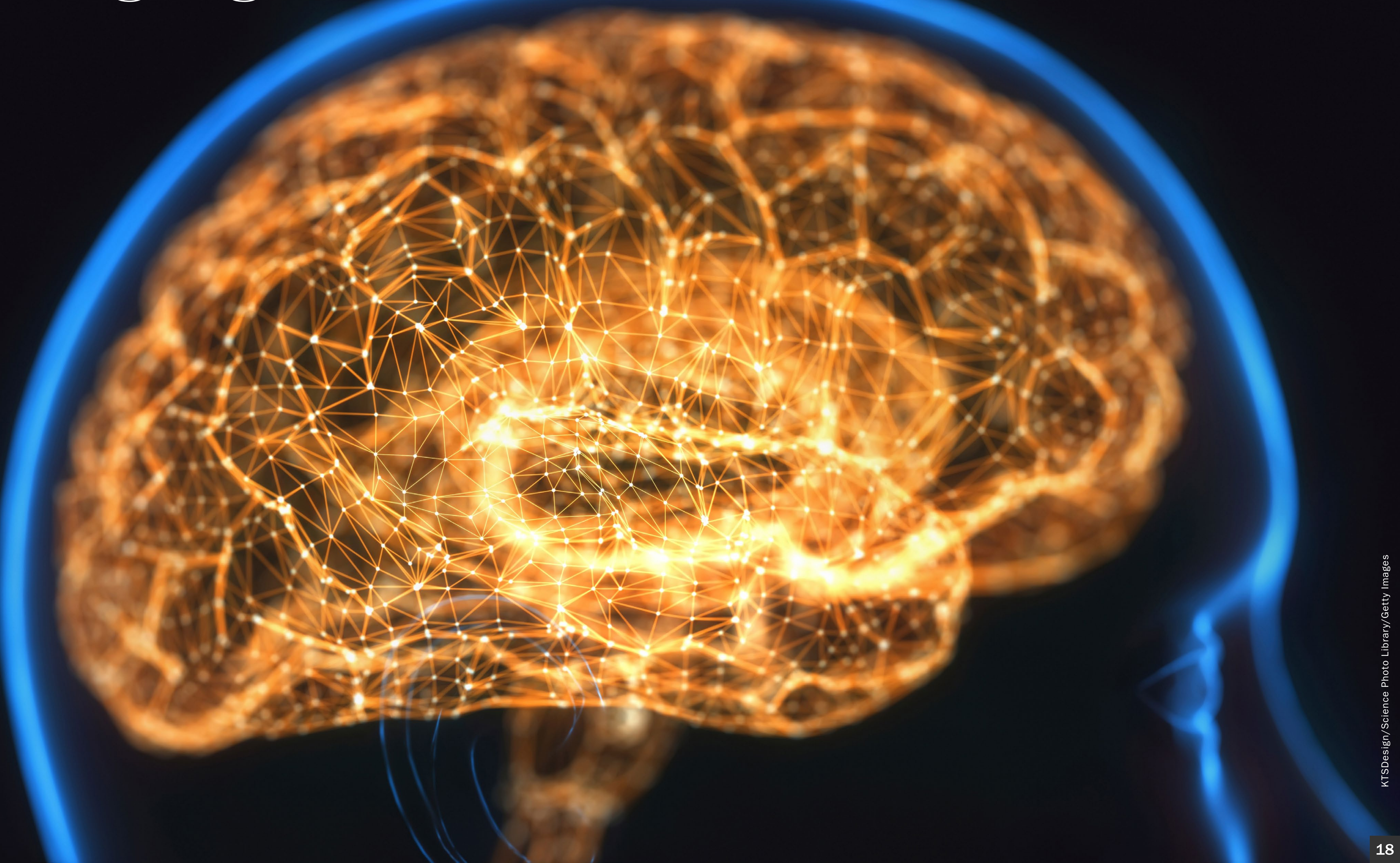
FU: We know that things are changing a lot when people are at home. Being able to work from home has allowed some long-distance partners to spend more time together or even live together. But for partners who do not live together and do not have that option of working remotely, difficulties in travel may lead to even less time together. For those living with their partner, more time spent together at home may not necessarily lead to more and more satisfying or pleasurable sex. Being quarantined, practicing social distancing, having financial difficulties, or working from home could all lead to strains in the relationship. Loss of or the instability of child care because of the pandemic can restrict the sex lives of those who are parents.

HERBENICK: Certainly people who do not live with partners have, by and large, been more constrained in partnered sex over the past two years, with some relaxation of that since the widespread availability of vaccines and vaccine boosters. But ultimately we don't live in a vacuum, and our sex lives don't occur in a vacuum, so there are myriad factors. The past two years have also brought lots of grief for people who have lost family members to COVID. Many people are dealing with long COVID and related health challenges, job loss and financial strain. And more people of all ages are dealing with anxiety and depression since the pandemic. So these all have influences on sexual interest and sex drive, too. M

How Brains Seamlessly Switch between Languages

Bilingual people engage the same brain region that monolingual individuals use to put together words—even when combining different languages

By Daisy Yuhas



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Billions of people worldwide speak two or more languages. (Although the estimates vary, many sources assert that more than half of the planet is bilingual or multilingual.) One of the most common experiences for these individuals is a phenomenon that experts call "code switching," or shifting from one language to another within a single conversation or even a sentence.

Last November, Sarah Frances Phillips, a linguist and graduate student at New York University, and her adviser Liina Pylkkänen published findings from brain imaging that underscore the ease with which these switches happen and reveal how the neurological patterns that support this behavior are very similar in monolingual people. The new study reveals how code switching—which some multilingual speakers worry is "cheating," in contrast to sticking to just one language—is normal and natural. Phillips spoke with Mind Matters editor Daisy Yuhas about these findings and why some scientists believe bilingual speakers may have certain cognitive advantages.

[*An edited transcript of the interview follows.*]

Can you tell me a little bit about what drew you to this topic?

I grew up in a bilingual household. My mother is from South Korea; my dad is African-American. So I grew up code switching a lot between Korean and English, as well as different varieties of English, such as African-American English and the more mainstream, standardized version.

When you spend a lot of time code switching, and then you realize that this is something that is not well understood from a linguistic perspective, nor from a neurobiological perspective, you realize, "Oh, this is open territory."

Most of the world operates with two or more languages. We should have models that tell us how brains operate not only within a single language but also across languages. We need to have a better understanding of what typical bilingual behavior and brain processes look like rather than relying on monolingual models of how languages are processed in the brain. Those single-language models, potentially, could cause people who are bilingual to be misdiagnosed with processing deficits just because they're doing something that doesn't fit what monolingual people typically do.

Rather than calling them deficits, some researchers have argued that there is a "bilingual advantage." Can you explain that idea?

The claim—and there's debate around it that makes it kind of a hot topic—is that bilingual people exhibit some kind of cognitive advantage, compared with their monolingual peers. This comes out of work done by Ellen Bialystok of York University [in Toronto], who saw that bilingual speakers were faster at doing cognitively demanding tasks, such as a psychological test where you have to inhibit some information to be able to successfully complete an assignment. These kinds of tasks are not necessarily linguistic in function; they tap into other things that we typically use on a day-to-day basis, such as attention and working memory.

Could code switching relate to possible memory and attention benefits?

One recent idea about improved cognitive functioning, which comes from work by researchers such as Judith Kroll of the University of California, Irvine, is that social aspects of language switching—such as deciding when and how you switch—could help explain potential benefits. Let's say you have a Spanish-English bilingual person talking to another Spanish-English bilingual person. Well, that is actually the easiest mode of conversation for them both because they can use whatever words work in whatever ways they want to put those words together to convey thoughts and ideas that they have, right?

What's actually hard is when you're in a situation where you have to stick with just one language. Let's say, as a Spanish-English bilingual person, you're in conversation with someone who speaks only English or only Spanish. In one hypothesis, the adaptive control hypothesis, the bilingual individual has to work really, really hard to make this conscious effort to suppress a language to communicate effectively with one monolingual person versus another fellow bilingual person.

> **"One of the things that I want people to know and understand is that code switching is very natural for bilingual people."**
> *—Sarah Frances Phillips*

Current ideas about the bilingual brain suggest that both languages are always accessible, even when the bilingual person is speaking with a monolingual person. So in specific social contexts, bilingual people have to further develop their working memory and attention skills to prevent switching to the language that the monolingual speaker would not understand.

What did you do in your new study?

I was really interested in looking at what happens in the brain when bilingual people switch languages as they compose words together. We gathered data from 20 English-Korean bilingual and biliterate participants, meaning they're able to read, write, speak and listen in both Korean and English. They each did more than 700 trials. And we used a technique called magnetoencephalography, or MEG, to track brain activity.

We presented participants a subject and intransitive verb [forms of speech that combine in the same way in both languages] to observe brain activity when these words combine. So in monolingual speakers, when we get something like "icicles" and "melt," it creates a greater peak of activity in a part of the brain called the left anterior temporal lobe because these words combine. But if we use "melt" and "jump" or other verbs, we don't see this effect, because those words don't combine into something meaningful.

What did you find when you did this test on bilingual people?

We replicated what's found in monolingual people: So when "melt" is in the context of "icicles," we see increased activity when compared with "jump"—and we see recruitment of the left anterior temporal lobe. We found this both in language switching [between English and Korean] and orthography [with Roman and Korean characters]. We're manipulating the language, as well as the representation of these words.

In other words, the brain activity looks a lot like what occurs in people who speak just one language. What does that tell us about code switching?

The fact that the left anterior temporal lobe is able to combine these concepts in meaningful ways without slowing down, without being affected by where these concepts are coming from or how they're being presented to us, tells us that our brains are able to do this kind of process naturally, and so we shouldn't shy away from it.

One of the things I want people to know and understand is that code switching is very natural for bilingual people. Asking us to maintain a single language is harder. I think that while most bilingual individuals have a negative attitude toward code switching—they think that it's bad or that we should stick to one language—it's not actually bad for our brain. I think that it's important to recognize that just because something doesn't look like monolingual behavior doesn't mean it's deviant. **M**

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NEUROSCIENCE

How Our Brain Preserves Our Sense of Self

One brain region is crucial for our ability to form and maintain a consistent identity both now and when thinking about the future

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We are all time travelers. Every day we experience new things as we travel forward through time. In the process, the countless connections among the nerve cells in our brain recalibrate to accommodate these experiences. It's as if we reassemble ourselves daily, maintaining a mental construct of ourselves in physical time, and the glue that holds together our core identity is memory.

Not only do we travel in physical time; we also experience mental time travel. We visit the past through our memories and then journey into the future by imagining what tomorrow or next year might bring. When we do so, we think of ourselves as we are now, remember who we once were and imagine how we will be.

A new study, published in the journal *Social Cognitive and Affective Neuroscience* (*SCAN*), explores how a specific brain region helps to knit together memories of the present and future self. Injury to that area leads to an impaired sense of identity. The region—called the ventral medial prefrontal cortex (vmPFC)—may produce a fundamental model of our self and place it in mental time. In doing so, this study suggests, it may be the source of our sense of self.

Psychologists have long noticed that our mind handles information about one's self differently from other details. Memories that reference the self are easier to recall than other forms of memory. They benefit from what researchers have called a self-reference effect (SRE), in which information related to one's self is privileged and more salient in our thoughts. Self-related memories are distinct from both episodic memory, the category of recollections that pertains to specific events and experiences, and semantic memory, which connects to more general knowledge, such as the color of grass and the characteristics of the seasons.

SREs, then, are a way to investigate how our sense of self emerges from the workings of the brain—something multiple research groups have studied intensely. For example, previous research employed functional magnetic resonance imaging (fMRI), a method that measures blood flow as a measure of brain activity, to identify regions that were activated by self-reference. These studies identified the medial prefrontal cortex (mPFC) as a brain region related to self-thought. The mPFC can be further divided into upper and lower regions (called dorsal and ventral, respectively), which make different contributions to self-related thought. The dorsal section plays a role in distinguishing self from other and appears to be task-related, whereas the ventral section, the vmPFC, contributes more to emotional processing.

In the new *SCAN* study, the researchers used the self-reference effect to assess memories of present and future selves among people with brain lesions to the vmPFC. The scientists worked with seven people who had lesions to this area and compared them with a control group made up of eight people with injuries to other parts of the brain, as well as 23 healthy individuals without brain injury. By comparing these groups, the scientists could investigate whether brain lesions in general or those to the vmPFC specifically might affect SREs. All people in the study underwent a thorough neuropsychological evaluation, which confirmed that they were within normal ranges for a variety of cognitive assessments, including measures of verbal fluency and spatial short-term memory. The researchers then asked the participants to list adjectives to describe themselves as well as a well-known celebrity, both in the present and 10 years in the future. Later, the participants had to recall these same traits.

The researchers discovered that people in their control group could recall more adjectives linked to themselves in the present and future than adjectives linked to the celebrity. In other words, they found that the self-reference effect extends to both the future as well as the present self. Although there was some variation in this group—people with brain injuries were somewhat less able to recall details about their future self when compared with nonbrain-injured participants—the self-reference effect still applied.

Results were distinctly different, however, for the participants with injury to the vmPFC. People with lesions in this area had little or no ability to recall references to the self, regardless of the context of time. Their identification of adjectives for celebrities in the present or future was also significantly impaired when compared with the rest of the participants. In addition, people with vmPFC lesions had less confidence about an individual's ability to possess traits than other people in the study. All of this evidence points to a central role for the vmPFC in the formation and maintenance of identity.

The new findings are intriguing for several reasons. Brain lesions can help us understand the normal function of the brain region involved. Lesions of the vmPFC are associated with altered personality, blunted emotions, and a number of changes in emotional and executive function. Injury to this area is most often associated with confabulations, that is, false memories that are told with great confidence. While it may be tempting for someone to perceive confabulation as deliberate or creative falsehood, people who confabulate are unaware their stories are false. Instead it is possible their confusion could stem from misfunctioning memory retrieval and monitoring mechanisms.

More broadly, the study helps to elucidate how self-related memories necessary to maintain our core sense of identity depend on the function of the vmPFC. But what about our past selves? Curiously, in previous studies that asked people to consider their past selves, there was no more activation of the mPFC than when considering someone else. Our past selves seem foreign to ourselves, as if they were another individual. One idea that scientists have put forward to understand this distinction is that perhaps we are not very kind in our judgments of our past selves, and we may use our past primarily to construct a positive self-image in the present. Put another way, because we may recognize flaws in our past self's behavior, we tend to distance ourselves from the person we once were.

Putting the present and future into the spotlight, then, is central to understanding the way our brain and thoughts build our current identities. In many ways, it makes sense that the mPFC is important in this process of recalling present details and imagining future ones that build on our recollections. The prefrontal cortex, including the mPFC, forms a network that is involved in future planning. That network includes the hippocampus, a brain structure that is central to episodic memory formation and that can track moments as sequential events in time. In past work, researchers have found that manipulating the activity of the hippocampus alters creative and future imaginings, which suggests an important role for brain structures supporting memory in imagining the future. In fact, while we often think of memory as the brain's accurate and dispassionate recording device, some scholars have characterized it as a form of imagination.

The importance of future thought to the human condition is embodied in the mythological figure Prometheus (whose name means "Forethinker"), patron of the arts and sciences. According to Greek legend, he shaped humans out of clay and bestowed them with fire and the skills of craftsmanship—acts that illustrate the power of imagining a novel future. Although there is debate as to whether thinking about the future is an exclusively human feature—birds such as Western scrub jays, for example, appear to anticipate and plan for future food needs—it is clear that future thought has played a significant role in human evolution. This ability may have contributed to the development of language, and it has a key role in human interactions, where the vmPFC is central to evaluating and taking advantage of social context. Thanks to this new research, we have a better idea than ever before of where this core ability is constructed in the brain.

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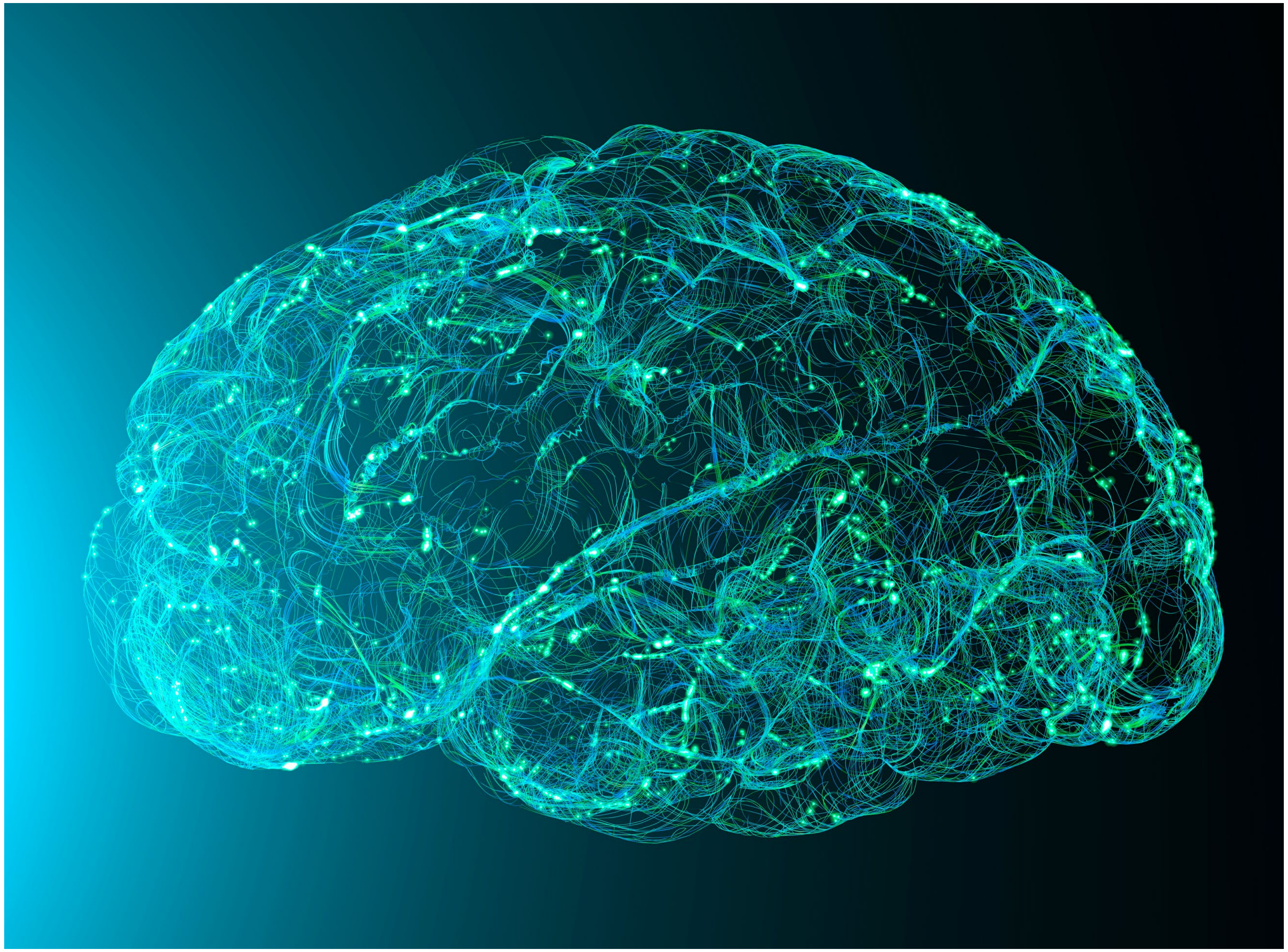
Michael Levin is a biology professor and director of the Allen Discovery Center at Tufts University.

EVOLUTION

New Clues about the Origins of Biological Intelligence

A common solution is emerging in two different fields: developmental biology and neuroscience



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In the middle of his landmark book *On the Origin of Species,* Charles Darwin had a crisis of faith. In a bout of honesty, he wrote, "To suppose that the eye with all its inimitable contrivances for adjusting the focus to different distances, for admitting different amounts of light, and for the correction of spherical and chromatic aberration, could have been formed by natural selection, seems, I confess, absurd in the highest degree." While scientists are still working out the details of how the eye evolved, we are also still stuck on the question of how intelligence emerges in biology. How can a biological system ever generate coherent and goal-oriented behavior from the bottom up when there is no external designer?

In fact, intelligence—a purposeful response to available information, often anticipating the future—is not restricted to the minds of some privileged species. It is distributed throughout biology, at many different spatial and temporal scales. There are not just intelligent people, mammals, birds and cephalopods. Intelligent, purposeful problem-solving behavior can be found in parts of all living things: single cells and tissues, individual neurons and networks of neurons, viruses, ribosomes and RNA fragments, down to motor proteins and molecular networks. Arguably, understanding the origin of intelligence is the central problem in biology—one that is still wide open. In this piece, we argue that progress in developmental biology and neuroscience is now providing a promising path to show how the architecture of modular systems underlies evolutionary and organismal intelligence.

Biologists are trained to focus on the mechanisms of living systems and not on their purpose. As biologists, we are supposed to work out the "how" rather than the "why," pursuing causality rather than goals. The "why" is not only always present but is precisely what drives specific "how"s to be chosen, enabling organisms to survive by selecting and exploiting specific mechanisms out of an astronomically large space of possibilities. In the case of the human eye, for example, the optical properties of the lens only make sense if they help focus the light on the retina. If you don't ask why the lens is transparent, you will never understand its function, no matter how long you study how it becomes transparent.

In fact, the problem of understanding how intelligence emerges is becoming more acute with the "omics" revolution, which is generating systematic, quantitative data on genomes, transcriptomes, proteomes and connectomes. Biological systems are being dissected into their ultimate complexity, but no magic answer is appearing at the end of the tunnel. The race to big data is not providing a better explanation of living systems. If anything, it's making it harder.

Modern biology faces a fundamental knowledge gap when trying to explain meaningful, intelligent behavior. How can a system composed of cells and electrical signals generate a well-adapted body with behavior and mental states? If cells are not intelligent, how can intelligent behavior emerge from a distributed system composed of them? This fundamental mystery permeates biology. All biological phenomena are, in a sense, "group decisions" because organisms are made of individual parts—organs, tissues, cells, organelles, molecules. What properties of living systems enable components to work together toward higher-level goals?

A common solution is emerging in two different fields: developmental biology and neuroscience. The argument proceeds in three steps. The first rests on one of natural selection's first and best design ideas: modularity. Modules are self-contained functional units like apartments in a building. Modules implement local goals that are, to some degree, self-maintaining and self-controlled. Modules have a basal problem-solving intelligence, and their relative independence from the rest of the system enables them to achieve their goals despite changing conditions. In our building example, a family living in an apartment could carry on their normal life and pursue their goals, sending the children to school, for example, regardless of what is happening in the other apartments. And in the case of the body, organs such as the liver operate with a specific low-level function, such as controlling nutrients in the blood, in relative independence with respect to what is happening, say, in the brain.

The second step in the argument is that modules can be assembled in a hierarchy: lower-level modules combine to form increasingly sophisticated higher-levels modules, which then become new building blocks for even higher-level modules, and so on. In our apartment building, families could belong to a local association, like a chapter of a political party, whose goals could be to ensure the future welfare of all the families in the area. And this party could belong to a parliament, whose goal could be to shape the policy of the entire country, and so on. In biology, different organs could belong to the same body of an organism, whose goal would be to preserve itself and reproduce, and different organisms could belong to a community, like a beehive, whose goal would be to maintain a stable environment for its members. Similarly, the local metabolic and signaling goals of the cells integrate toward a morphogenetic outcome of building and repairing complex organs. Thus, increasingly sophisticated intelligence emerges from hierarchies of modules.

This may seem to solve the problem, except that hierarchical modularity still does not explain how evolution, changing solely one element at a time at a lower level, can ever manipulate the upper levels. Given that the upper levels are built with lower levels, wouldn't you still need to modify a slew of things at the same time to change an upper-level module? A third step in our argument addresses this problem: each module has a few key elements that serve as control knobs or trigger points that activate the module. This is known as pattern completion, where the activation of a part of the system turns on the entire system. In our apartment building, the family would have one central figure, let's say, one of the parents, who would represent the family in meetings and engage it when needed. These trigger points serve to represent the entire module and thus enable these modules to be activated, altered, inactivated or deployed in novel circumstances without having to manipulate or re-create all their parts. Moreover, pattern completion naturally emerges from systems of interconnected elements with interactions among the elements.

In recent years researchers have found evidence for pattern completion in both neural circuits and developmental biology. For example, when Luis Carrillo-Reid and his colleagues at Columbia University studied how mice respond to visual stimuli, they found that activating as few as two neurons in the middle of a mouse brain—which contains more than 100 million neurons—could artificially trigger visual perceptions that led to particular behaviors. These fascinating pattern-completion neurons activated small modules of cells that encoded visual perceptions, which were interpreted by a mouse as real objects. Similarly, in work published in 2018, Michael Levin of Tufts University and Christopher Martyniuk of the University of Florida reviewed data showing how triggering a simple bioelectric pattern in nonneural tissues induced cells to build an eye or other complex organs in novel locations, such as on the gut of a tadpole.

The idea of hierarchical modularity to explain biological intelligence has been explored before by economist Herbert Simon, neuroscientist Valentino Braitenberg, computer scientist Marvin Minsky, evolutionary biologists Leo Buss, Richard Dawkins and David Haig, and philosopher Daniel C. Dennett, among many others. These recent experiments from developmental biology and neuroscience can now provide a common mechanism of how this could work via key nodes that generate pattern completion. While there is still much to learn about how pattern-completion units work, they could provide a solution to the problem of how to repurpose a system of modules without having to change it all. The manipulation of local goal-pursuing modules, to make them cooperate at multiple scales of organization in the body, is a powerful engine. It enables evolution to exploit the collective intelligence of cell networks, using and recombining tricks discovered at the lower level while operating with robustness despite noise and uncertainty.

Like a ratchet, evolution can thus effectively climb the intelligence ladder, stretching all the way from simple molecules to cognition. Hierarchical modularity and pattern completion can help understand the decision-making of cells and neurons during morphogenesis and brain processes, generating well-adaptive animals and behavior. Studying how collective intelligence emerges in biology not only can help us better understand the process and products of evolution and design but could also be pertinent for the design of artificial-intelligence systems and, more generally for engineering and even the social sciences.

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NEUROSCIENCE

People Love the Brain for the Wrong Reasons

Our fascination with brain-based explanations of psychology arises from intuitive ideas about the separation of mind and body—ideas unsupported by science

Ivan Bajic/iStock/Getty Images

How can a cellist play like an angel? Why am I engrossed in my book when others struggle with reading? And while we're at it, can you tell me why my child won't stop screaming?

Now neuroscience offers the answers—or so say the news headlines. The brains of musicians "really do" differ from those of the rest of us. People with dyslexia have different neural connections from people without the condition. And your screaming toddler's tantrums originate from her amygdala, a brain region linked to emotions. It's all in the brain!

Neuroscience is fascinating. But it is not just the love of science that kindles our interest in these stories. Few of us care for the technical details of how molecules and electrical charges in the brain give rise to our mental life. Furthermore, invoking the brain does not always improve our understanding. You hardly need a brain scan to tell that your toddler is enraged. Nor is it surprising that an amateur cellist's brain works differently than Yo-Yo Ma's does—or that the brains of typical and dyslexic readers differ in some way. Where else would those differences reside?

These sorts of science news stories speak to a bias: As numerous experiments have demonstrated, we have a blind spot for the brain. In classic work on the "seductive allure of neuroscience," a team of researchers at Yale University presented participants with a psychological phenomenon (for instance, children learning new words), along with two explanations. One invoked a psychological mechanism, and the other was identical except it also dropped in a mention of a brain region. The brain details were entirely superfluous—they did nothing to improve the explanation, as judged by neuroscientists. Yet laypeople thought they did, so much so that once the brain was invoked, participants overlooked gross logical flaws in the accounts.

Why people fall in love with brain-based explanations, however, has remained a scientific mystery. Past studies make it clear that neither the use of vivid brain images, nor the complexity, nor the science jargon alone drives people's preference for brain explanations of psychological phenomena. Although they play a role, the fascination with the brain remains even when scientists remove these factors. Reductionism, the tendency to explain scientific phenomena at one level by appealing to a more basic level (such as reducing biology to chemistry), presents another explanation. Researchers have found that people do, indeed, prefer reductive explanations. But the preference to reduce psychology to neuroscience is particularly strong—more so than in other scientific domains.

Several recent investigations by my lab shed new light on the mystery. In a series of studies, my colleagues and I invited hundreds of participants—all nonscientists—to "play clinician." They had to diagnose a clinical condition using either a brain or behavioral test. The two tests were equally likely to provide a diagnosis. In every case, however, people thought that the brain test was more informative, and they drew inferences that went far beyond what the test actually suggested. These assumptions, in turn, revealed that people hold beliefs about the brain that may help to explain why they fall for neuroscientific explanations in the first place.

When people think a depression diagnosis involved a brain scan, their essentialist intuition that "what's in the body is innate" makes them perceive the patient's depression as inborn and unchangeable.

To imagine these experiments, suppose that you, as a clinician, had to diagnose a patient who might have autism. The diagnostic test focuses on a well-studied characteristic of the condition: that people with autism struggle to infer what other people might know and think in a given situation as separate from their own knowledge and thoughts. You present your patient with a video featuring one character, Bob, moving the car keys of another character, Jane, when she isn't looking. The patient must predict whether Jane will search for her keys where she previously left them or where Bob put them (a fact known only to the patient). Because many people with autism assume others have the same knowledge they themselves have, when a patient with autism is shown this video, the patient will expect Jane to search for her keys where Bob left them. Your goal is to detect whether your patient is surprised when Jane instead searches the area where she put her keys.

At this point, you have a choice: You can observe the patient's reaction using a behavioral method, such as eye-tracking technology. With this approach, you can detect surprise if the patient stares at Jane for a long time. Or you can use a brain-monitoring technique where a "spike" in activity indicates surprise. Which test is better?

In truth, the two tests are equivalent. But, as you might expect, most people favor the brain test. To find out why, my colleagues next asked participants to consider a different scenario. Once again, the patient was suspected of having autism, but this time, the symptom participants were looking for was a sensation: a hypersensitivity to sound, which causes people with autism to get distracted by noises. As before, this condition was diagnosed using either behavior (where eye movement reveals the patient's distraction) or brain monitoring (where distracting noises would increase brain activity). But this time, the preference for brain tests was far weaker.

Why do people prefer the brain-based evidence when they consider someone's thoughts more than when they focus on sensations? My colleagues and I suggest the difference reflects how people perceive thoughts on the one hand and sensations on the other. People tend to interpret sensations as "embodied"—that is, we link them to specific body parts. We hear with our ears and see with our eyes. But thoughts, in contrast, seem strangely ethereal, even though we rationally know they "live" in the brain. This tendency to view the mind as distinct from the body is called dualism. My group has investigated this intuition extensively in past work and found it slips into many of our tacit assumptions about cognition. For example, people suspect that thoughts are more likely than sensations to remain in the afterlife but less likely to show up in a brain scan. So science notwithstanding, at heart we are closet dualists—we conceive of the mind as distinct from the body.

Dualism could help to explain the seductive allure of neuroscience. That's because our dualist intuitions put us in an uncomfortable position whenever we encounter evidence that our ethereal thoughts interact with the body. In a recent experiment, when I asked people to reason about the causes of everyday actions, such as reaching one's arm toward a coffee mug, people rated thoughts (thinking about coffee) as more surprising causes of their arm's action than perceptions (seeing the coffee). So although we readily attribute people's actions to their thoughts, deep down, this effect of mind on matter is unsettling. But brain-based explanations alleviate this tension. If it is the brain—part of one's body—that made one's hand (body) move, then there are no more ghostly interactions between mind and matter—mystery solved! Brain explanations are seductive, I argue, because they alleviate a mind-body tension created by our dualist intuition. And because this dualist tension is particularly acute for thoughts, the allure of the brain explanation is stronger for thinking than sensing, which we align with the body.

There is more to our infatuation with the brain than just dualism, however. Not only do many individuals consider brain-based explanations more attractive, but my lab has also found evidence that people tend to believe information linked to the brain can reveal a person's inborn "essence." So when participants learn that a woman's depression was diagnosed with a brain test, they incorrectly conclude that depression runs in her family and that the symptoms will last a long time. If her condition was diagnosed with a behavioral assessment, participants are less convinced of a family connection or that symptoms will persist for a lengthy period. (In reality, the test type has no bearing on these matters.)

We believe these findings reflect a second principle of intuitive psychology: Essentialism is the belief that living things are what they are because of an immutable essence that resides in each person's body. When people think a depression diagnosis involved a brain scan, their essentialist intuition that "what's in the body is innate" makes them perceive the patient's depression as inborn and unchangeable. Essentialism, then, offers another explanation for the brain's seductive allure.

On a rational level, we all know that thinking happens in the brain and that our brain isn't our immutable essence or destiny. But as the studies in my lab make clear, our intuitive psychology suggests otherwise. The consequences are far-reaching. Not only do these beliefs kindle our irrational love affair with the brain, but they can also seriously sway our thinking about psychological disorders and promote stigma toward patients.

Thankfully, our rationality can keep these biases at bay, promoting better science literacy and a kinder society. To do so, we must face our biases by taking a hard look within.

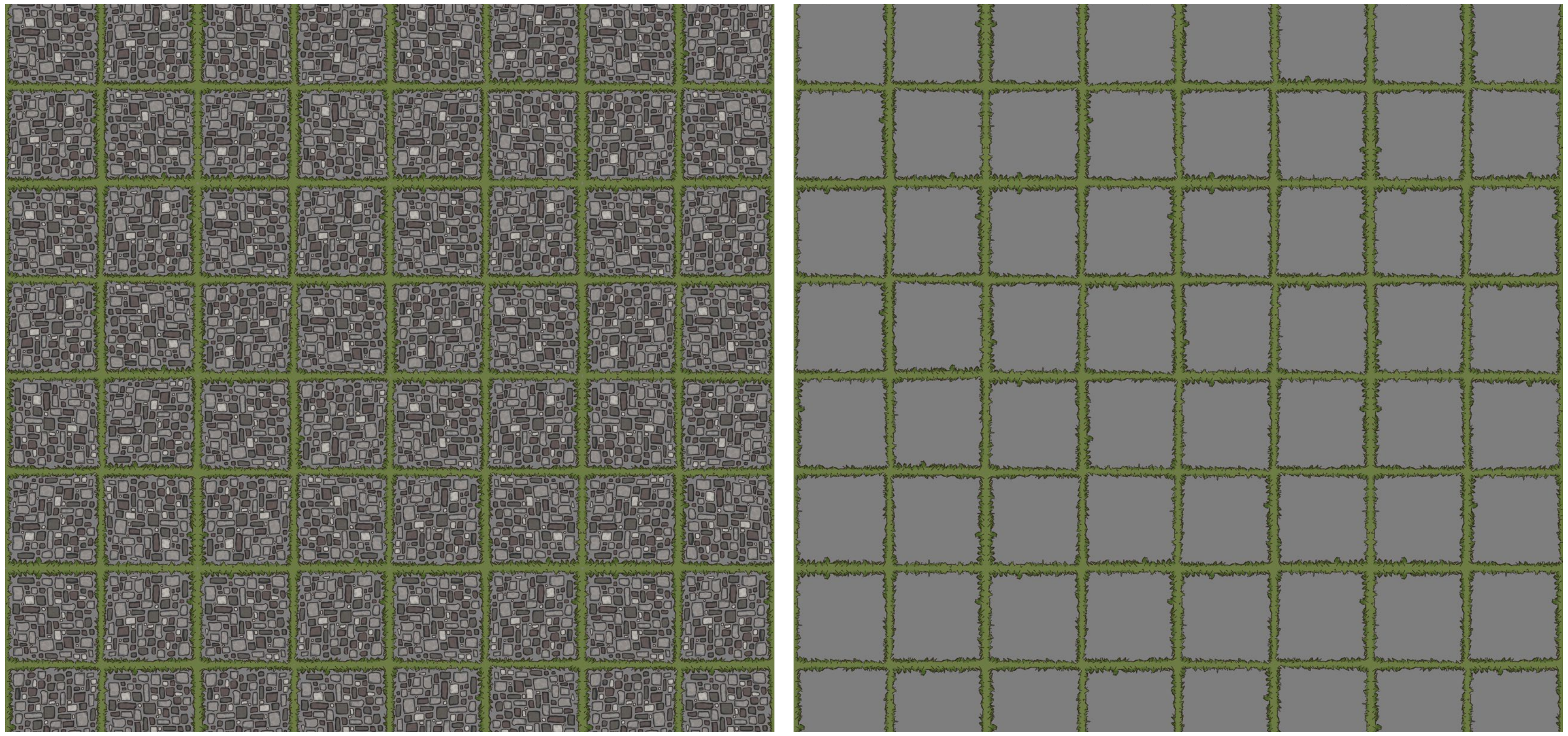
Susana Martinez-Conde and **Stephen Macknik** are professors of ophthalmology at the State University of New York and the organizers of the Best Illusion of the Year Contest. They have co-authored *Sleights of Mind: What the Neuroscience of Magic Reveals about Our Everyday Deceptions* and *Champions of Illusion: The Science behind Mind-Boggling Images and Mystifying Brain Puzzles.*

Here Be Dragons

A gaming cartographer discovers an uncharted perceptual realm

On December 2021, Lesha Porche, an illustrator and graphic artist based in Florida, stumbled on an illusion that would become an online viral phenomenon and leave many perceptual experts scratching their heads. Porche's illustration work often entails drawing maps for tabletop roleplaying games, such as Dungeons & Dragons. This time, she set out to produce a courtyard for the players, and initially noticed nothing amiss. Porche decided on a repeating pattern of tiles edged in grass. She copied, rotated, flipped and randomly pasted tiles out to an 8 x 8 grid. Just as she was ready to use the image she created, she zoomed out to observe the full effect. "I pretty much broke my brain trying to figure out what I'd just made," she recalls.

In the Warped Grid Illusion unveiled by Porche's work, a crisscrossing grid over a tile pattern seems to bend and deform in front of the observer's eyes. In reality, all grid lines are perfectly straight. Moreover, the distortion effect is ever elusive to the onlooker: each and every line that looks warped in one's visual periphery becomes rectilinear when viewed directly.



Left: Warped Grid Illusion. *Right:* Grid pattern without the "cobblestone tiles."

Lesha Porche

"I get headaches from illusions, so I was surprised I had made one so dynamic completely by accident," says Porche. "My friend Mike Johnson pointed out [that there is] a sort of secret path in the cobble pattern, and this is where the eye keeps 'jumping,'" she explains. Indeed, the grass-etched grid pattern does not appear to warp randomly, but instead seems to follow the "chains" of pale cobblestones depicted in the tiles. If that is the case, Porche's creation could be related to Hybrid Image illusions, in which two superimposed images—one containing fine and the other containing coarse visual details, also known as high and low spatial frequencies—result in competing perceptions. The former is best experienced at close range, and the latter from afar (or out of the corner of one's eye).

In the Warped Grid Illusion, the high spatial frequencies arise from the rectilinear grid, and the low spatial frequencies from the designs formed by cobblestones of like colors. Observed directly, the high spatial frequencies from the grid itself dominate, making its lines look straight. In the visual periphery, the low spatial frequencies from the cobblestone sets take over, warping the grid design with distortions worthy of a Mage's 7th level illusion spell. A similar phenomenon is thought to explain why Mona Lisa's smile seems subdued when observed directly, but wider and more obvious when viewed peripherally.

SCIENTIFIC AMERICAN MIND

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