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Traumatic events like pandemics can spur transformative psychological growth

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WITH COVERAGE FROM nature

FROM THE EDITOR

LIZ TORMES

The Glimmer of a Silver Lining

Months of pandemic lockdowns, an economic crisis and necessary social upheaval are taxing each and every one of us. As *Wired* writer Matt Simon outlined in an article in early June, our bodies are programmed to deal with short spurts of stress. Longer hauls of strain amp up levels of the hormones cortisol and adrenaline and lead to a host of problems from anxiety to insomnia and—in the extreme—even Cushing's syndrome. But we don't have to stress out over the stress. Author and psychologist Steve Taylor writes in this issue that experiencing trauma and turmoil can lead to positive effects in some people. So-called post-traumatic growth leads nearly half of those who experience intensely stressful events to later find a new, more positive perspective on life. This transformation often includes a stark recognition of what truly matters and of what brings a sense of meaning to your existence. Despite their past hardships, those who report these positive effects feel that they end up in a better mental place than before their ordeal (see "The Coronavirus and Post-traumatic Growth").

Elsewhere in this issue, our Beautiful Minds columnist Scott Barry Kaufman talks with philosopher and professor Robyn Repko Waller about the scientific study of human free will (see "The Neuroscience of Free Will"). And researchers at Harvard University reveal how particular language strategies can improve conversations between individuals and groups that disagree with one another (see "The Right Way to Talk across Divides"). What a welcome outcome that would be.

Andrea Gawrylewski
Senior Editor, Collections
editors@sciam.com

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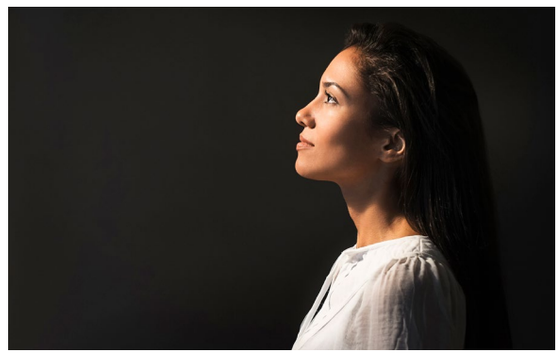

TOM GRILL *GETTY IMAGES*

On the Cover

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WHAT'S INSIDE

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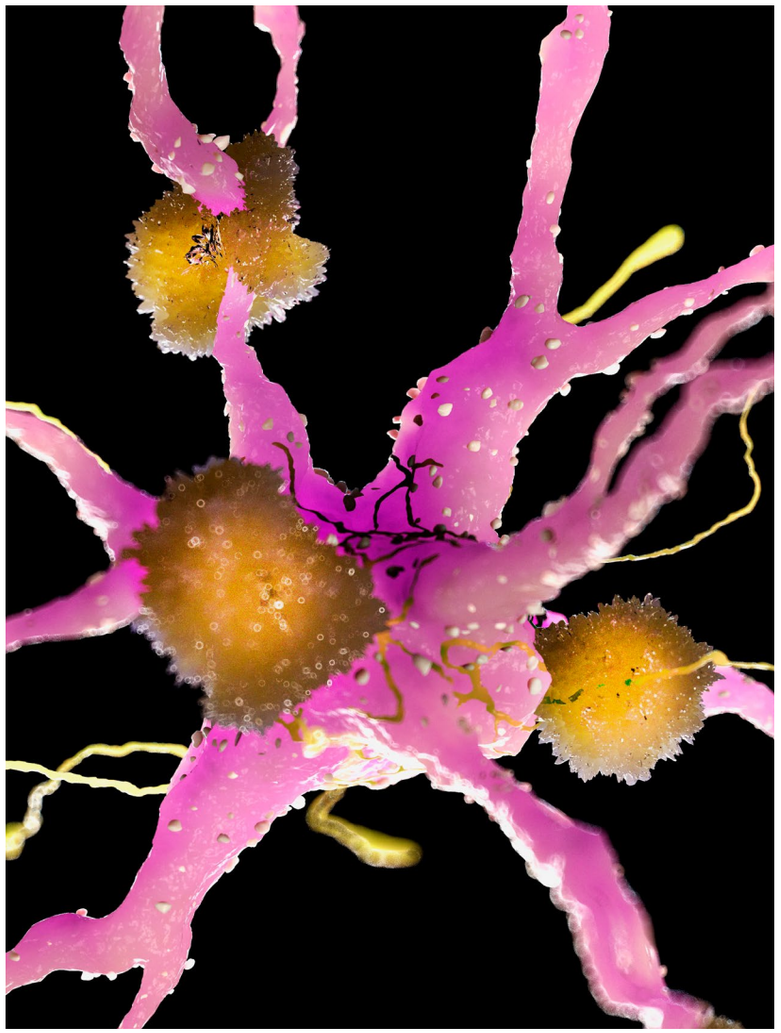

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NEWS

The Loneliness of the "Social Distancer" Triggers Brain Cravings Akin to Hunger

A study on isolation's neural underpinnings implies many may feel literally "starved" for contact amid the COVID-19 pandemic

OLIVER ROSSI GETTY IMAGES

Loneliness hurts. It is psychologically distressing and so physically unhealthy that being lonely increases the likelihood of an earlier death by 26 percent. But the feeling may serve a purpose. Psychologists theorize that it hurts so much because, like hunger and thirst, loneliness acts as a biological alarm bell. The ache of it drives us to seek out social connection just as hunger pangs urge us to eat. The idea is intuitively satisfying, yet it has long proved difficult to test in humans.

On March 26, however, just as the COVID-19 pandemic gripped the world, researchers at the Massachusetts Institute of Technology posted a preliminary report on bioRxiv. It was the first study in humans to show that both loneliness and hunger share signals deep in a part of the brain that governs very basic impulses for reward and motivation. The findings point to one telling conclusion: our need to connect is apparently as fundamental as our need to eat.

The extraordinary scientific timing of the paper's release—just as tens of millions of people were suddenly starved for contact—was far from intentional. When they began the work three years ago, neuroscientists Livia Tomova and Rebecca Saxe and their colleagues wanted to demonstrate how loneliness operates in the brain. They were inspired by similar research in animals and by the pioneering loneliness studies of the late University of Chicago psychologist John Cacioppo.

But enforced social isolation is so rare in healthy, nonincarcerated humans that it gave the team pause. "I sometimes struggled to articulate what that would be like in the real world," Saxe admits. "Why would that ever happen?" By the time the re-

searchers came to write their study this year, the unimaginable had become real. Now, Saxe says, "what feels most significant about this paper is that it's a way to step outside the experience we're having and look on it through a different lens."

This is "a tour de force paper," says psychologist Jamil Zaki of Stanford University, who was not involved in the research. He studies empathy and social interaction and is the author of *The War for Kindness: Building Empathy in a Fractured World.* "Speculatively, it suggests that chronic social isolation might be something like long-term undernourishment, producing a steady, aversive need that wears away at our well-being," Zaki says. "These findings give a name to what countless people are experiencing right now: social craving while staying at home to protect the public health."

The paper, which has not yet been peer-reviewed, describes a carefully designed experiment using functional magnetic resonance imaging (fMRI) to compare brain responses to loneliness and hunger. After a baseline brain scan, 40 adult participants underwent two 10-hour sessions: one in which they were deprived of food and another where they were denied social contact. The sessions served as control conditions for each other.

The social-isolation condition was challenging to arrange. Some people are lonely in a crowd, whereas others enjoy solitude. To induce not just objective isolation but subjective feelings of loneliness, the researchers had the participants spend their time from 9 A.M. to 7 P.M. in a sparsely furnished room at the laboratory without phones, laptops or even novels, in case fictional characters provided some social sustenance. Puzzles were allowed, as was preapproved nonfiction reading or writing. During the food-deprivation day, the subjects could not eat or drink anything but water over the same time frame.

Brain scanning immediately followed each deprivation session, yet measuring the relevant brain signals was also challenging. Tomova and Saxe focused on a midbrain region called the substantia nigra, a center of dopamine release involved with motivation and craving. Because an fMRI signal from the substantia nigra is indirect, the researchers designed a cue-induced craving task similar to what is used in addiction research. When drug addicts are shown cues associated with their substance of choice, "they show a really strong wanting response," Tomova says. "It's quite established that this triggers this dopaminergic response."

"These findings give a name to what countless people are experiencing right now: social craving while staying at home to protect the public health."

—Jamil Zaki

In the scanner, the participants saw images of their preferred forms of social interaction and of their favorite foods, as well as a control image of flowers. "We found that this brain area specifically responded to the cues after deprivation but only to cues of what they had been deprived of," Tomova says. The magnitude of the response correlated with the subjects' self-reports of how hungry or lonely they were, although feelings of hunger were consistently stronger.

Finally, the researchers used machine learning to confirm their findings. A software classifier trained to recognize neural patterns during fasting proved able to recognize similar neural patterns from the social-isolation condition even though it had never "seen" them. "This tells us that there seems to be an underlying shared neural signature between the two states," Tomova says. "Social contact is a very basic need."

Even before the COVID-19 pandemic, an obvious next question for the work was whether different forms of social media could satisfy the need for social connection. Saxe and Tomova were never able to get funding for such a study. It seems likely they will now. Tomova is already working with researchers at the University of Cambridge, where she will move in the fall, to see if social media use during the pandemic might be remediating feelings of loneliness. "Twenty years from now," Saxe says, "we will know what all the effects were of this experience we are having."

—Lydia Denworth

The Problem with Telling Children They're Better Than Others

There is a superior way to motivate kids and make them feel proud about their accomplishments

When parents ask, "What grade did you get?" there is a common follow-up question: "So who got the highest grade?" The practice of making such social comparisons is popular in all corners of the world, research shows. Many educators select and publicly announce the "best student" in a class or school. Adults praise children for outperforming others. Sports tournaments award those who surpass others. Last year the Scripps National Spelling Bee awarded winners a $50,000 cash prize and their own trophy—just for being better than others. Most social comparisons are so common in daily life that they are usually glossed over.

Social comparisons are well intentioned: we want to make children feel proud and to motivate them to achieve. As one writer for the Novak Djokovic Foundation noted, "Winning a game or being the best in the class gives children a good feeling about themselves and makes them proud," and it helps "children get motivated to take the next steps to achieve even bigger goals, such as jumping even further." Yet social comparisons can backfire: children may learn to always compare themselves with those around them and become trapped in a vicious cycle of competition.

One well-known strategy to eliminate social comparisons is to provide children with participation trophies. As the Dodo in Lewis Carroll's *Alice's Adventures in Wonderland* puts it: "Everybody has won, and all must have prizes." Such awards, however, may not abolish social comparisons: despite receiving the same trophy, children are sensitive to even minor differences in performance between themselves and others. High-performing children who receive the same prize as low-performing ones may feel unjustly treated and look down on the latter group. More generally, those who receive unwarranted rewards may come to believe that they are entitled to recognition and admiration. Indeed, lavishing children with praise can, in some cases, cultivate narcissism, research shows.

NICOLA TREE GETTY IMAGES

How, then, can we make children feel proud of themselves and motivate them without the unwanted side effects? We believe a better approach is to use temporal comparisons—encouraging children to compare themselves with their past selves rather than with others, such as by assessing how much they have learned or improved themselves. When children compare their current selves with their past selves, they do not compete with others.

We investigated this approach in a recent study and found it effective. First, we recruited a sample of 583 children from various elementary and secondary schools. To set up the test, we had the children do a reading-and-writing exercise designed to influence the kind of comparisons they would make: social comparisons, temporal comparisons or no comparison at all. For

example, in the social-comparison condition, a nine-year-old girl wrote, "I was better than my peers at singing. I can sing and others can't. I find myself really important. I love singing, I keep doing it, and I'm simply the best." By contrast, in the temporal-comparison condition, a 13-year-old girl wrote, "At first, I didn't have many friends. But at some point, I was done with it. So, I started sitting next to random people and they became my best friends. Now that I have that many friends I feel good and confident."

In the study, we found that children who compared themselves favorably to others or to their past selves all felt proud of themselves. Children who compared themselves with others, however, said they wanted to be superior to such people, whereas those who compared themselves with their past selves said they wanted to improve rather than be superior. Temporal comparisons shifted children's goals away from a desire for superiority and toward self-improvement.

What, then, can parents and teachers do with this knowledge? Research suggests several strategies. For one, parents and teachers can praise children's improvement over time ("You're getting the hang of it!") to let them know they are making progress and heading in the right direction. Also, teachers can create learning contexts that track children's progress over time, such as report cards that display their changes in learning and performance. By doing so, adults teach children that outperforming oneself is more important than outperforming others and that even small victories may be celebrated.

Of course, temporal comparisons are not a panacea; we should never push children to improve themselves relentlessly. The road toward self-improvement is paved with struggles and setbacks. Rather than making children feel bad for those failures, we should encourage them to embrace and learn from them—and thus help youngsters become better than they were before. We need to offer children more opportunities to make temporal comparisons, so they can see how much they have learned and how much they have grown. This strategy should allow them to "jump even further."

—Çisem Gürel and Eddie Brummelman

Marijuana May Not Lower Your IQ

Rigorous new studies should be able to settle the matter

Around the world, about 188 million people use marijuana every year. The drug has been legalized for recreational use in 11 U.S. states, and it may eventually become legal at the federal level. In a Gallup survey conducted last summer, 12 percent of American adults reported that they smoked marijuana, including 22 percent of 18- to 29-year-olds. Those are the stats. The consequences remain a mystery.

As access to marijuana increases—and while acceptance of the drug grows and perception of its harmfulness diminishes—it is important to consider the potential for long-term ill effects, especially in users who start young. One of marijuana's best-documented consequences is short-lived interference with memory. The substance makes it harder to get information into memory and, subsequently, to access it, with larger doses causing progressively more problems. Much less documented, however, is whether the drug has lasting effects on cognitive abilities. Finding the answer to that question is essential. Depending on the severity of any such effects and their persistence, marijuana use could have significant downstream impacts on education, employment, job performance and income.

There are plausible reasons why the teenage brain may be especially vulnerable to the effects of marijuana use. Natural cannabinoids play an essential role in brain cell migration and development from fetal life onward. And adolescence is a crucial age for finalizing brain sculpting and white matter proliferation. The hippocampi, paired structures in the temporal lobe that are crucial in the formation of new memories, are studded with cannabinoid receptors. THC, the main ingredient behind marijuana's "high," acts on the brain's cannabinoid receptors to mimic some of the effects of the body's endogenous cannabinoids, such as anandamide. The compound's effects are more persistent and nonphysiological, however. It may be throwing important natural processes out of balance.

A key report on marijuana appeared in 2012. It was issued by a research group that had tracked the development of 1,000 New Zealanders born in the city of Dunedin in the early 1970s. Having assessed measures of cognition and IQ when their subjects were three years old, the researchers recorded participants' use of the drug from their early teen years through their 30s. Whereas those who never used marijuana showed slight IQ increases over time, users experienced steady IQ declines proportional to how long and how much they had smoked. At age 38, users who had started young reported more problems with subjective thinking, and their close friends described them as having attention and memory difficulties. Those who smoked marijuana heavily as adolescents and later quit never fully returned to the baseline.

The effect involved all cognitive domains, from remembering lists of words to processing information, solving problems and paying attention. The three dozen people who had used the drug most persistently had an overall decline of around six to eight IQ points. That is a big deal. So you might think, "Case closed. Smoking dope makes you dopey." But not so fast.

In a world run by evil scientists, determining the effects of marijuana on IQ would be simple: A randomly selected half of the population would be exposed to the drug during adolescence, and the remainder would be given a placebo. Scientists could compare subjects' cognitive scores before and after marijuana use, and, presto, you would have your answer. For such answers in the real world, however, we rely on epidemiology, a branch of science that addresses population-level questions ethically. Two important longitudinal strategies for disentangling causes and consequences are large-scale cohort studies and twin designs.

The advantage of the former strategy, as used in the Dunedin study, is that each participant acts as his or her own control. Given that every child starts with a different IQ, it is simple to measure whether Johnny's or Janie's scores rise or fall over time in relation to their marijuana use (measured by individual accounts of the quantity, frequency and duration of that use).

The second strategy proceeds from a different logic. Because twins

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grow up with the same family backgrounds and are genetically very similar (nearly precisely so in identical twins), they form perfect experimental controls for each other. If Twin A smokes cannabis and Twin B does not, then researchers have a tightly controlled mini experiment that helps rule out confounding factors such as Dad's job or the alcoholism in Mom's family. With epidemiological twin studies, a researcher is able to look across an entire sample and summarize all the relevant effects.

Two such researchers are Nicholas Jackson of the University of Southern California and William Iacono of the University of Minnesota, who worked with their colleagues to examine data from two longitudinal studies of adolescent twins in California and Minnesota. The researchers measured the twins' intelligence between nine and 12 years of age, before any drug use, and did so again between ages 17 and 20. Exactly as in the Dunedin study, marijuana users had lower test scores and showed notable reductions in IQ over time. But in

Jackson and Iacono's analysis, marijuana use and IQ were completely uncorrelated, and IQ measures fell equally in the users and in the abstainers. Subsequent twin studies, including one performed with U.K. data by the Dunedin team, corroborated these findings of no relationship between marijuana use and a falling IQ.

How can we explain these discrepancies? First, young marijuana users are many times more likely to also use alcohol and other illicit drugs. And when epidemiologists factor binge drinking, nicotine and other drug use into their models, marijuana's cognitive effects evaporate. Thus, IQ decline seems more nonspecifically related to general substance use. But this observation does not explain why IQ also falls in nonusing twins of cannabis users. Jackson, Iacono and their colleagues noted that at baseline, prior to any substance involvement, future marijuana users in one of the two cohorts they examined already had significantly lower IQ scores. Put another way, cannabis did not drag down their IQ; it was already low.

Next, investigators uncovered shared underlying vulnerability factors that explained both marijuana use and IQ decreases. For example, behavioral traits such as impulsivity and excessive risk-taking predicted both substance use and lower IQ, as did being raised in a family that did not value education. Delinquent kids received lower grades because of their tendency to skip school and use drugs. So cannabis use was not a culprit in cognitive decline. A welter of inherited and environmental factors seemed to explain both.

How can we discern the truth among apparently convincing yet opposing sets of findings? The early-middle-aged subjects in New Zealand had used cannabis over a much longer time span than had the late-teen twins in Minnesota. Perhaps adolescent cannabis use has no detectable cognitive impact unless it occurs at very high levels or over many years. For now, investigators are eagerly awaiting data from the recently launched Adolescent Brain Cognitive Development (ABCD) study. ABCD is following 11,000 U.S. 10-year-olds in a national epidemiological sample with serial IQ testing and brain imaging to capture the trajectories of normal brain and IQ development prior to any substance use—and to document any longitudinal consequences of such use. This research has the potential to settle the issue of the relationship of adolescent marijuana use to changes in cognition. Scientists will begin to see meaningful results in the next few years, as these subjects reach their mid-teens.

Last year former Food and Drug Administration commissioner Scott Gottlieb warned about the potential harm embedded in "the great natural experiment we're conducting in this country by making THC widely available." His concerns return us to the core issue. Physicians and lawmakers need a more accurate sense of THC's effects on adolescent minds so that parents, teachers and social planners can respond preemptively to teenage marijuana use. If long-term cognitive effects are shown to be real, this conclusion should result in appropriate plans to restrict use through educational efforts and tough legal sanctions. On the other hand, if cognitive effects are transient or better explained by sociological phenomena, we can all take a step back and direct our efforts and resources elsewhere.

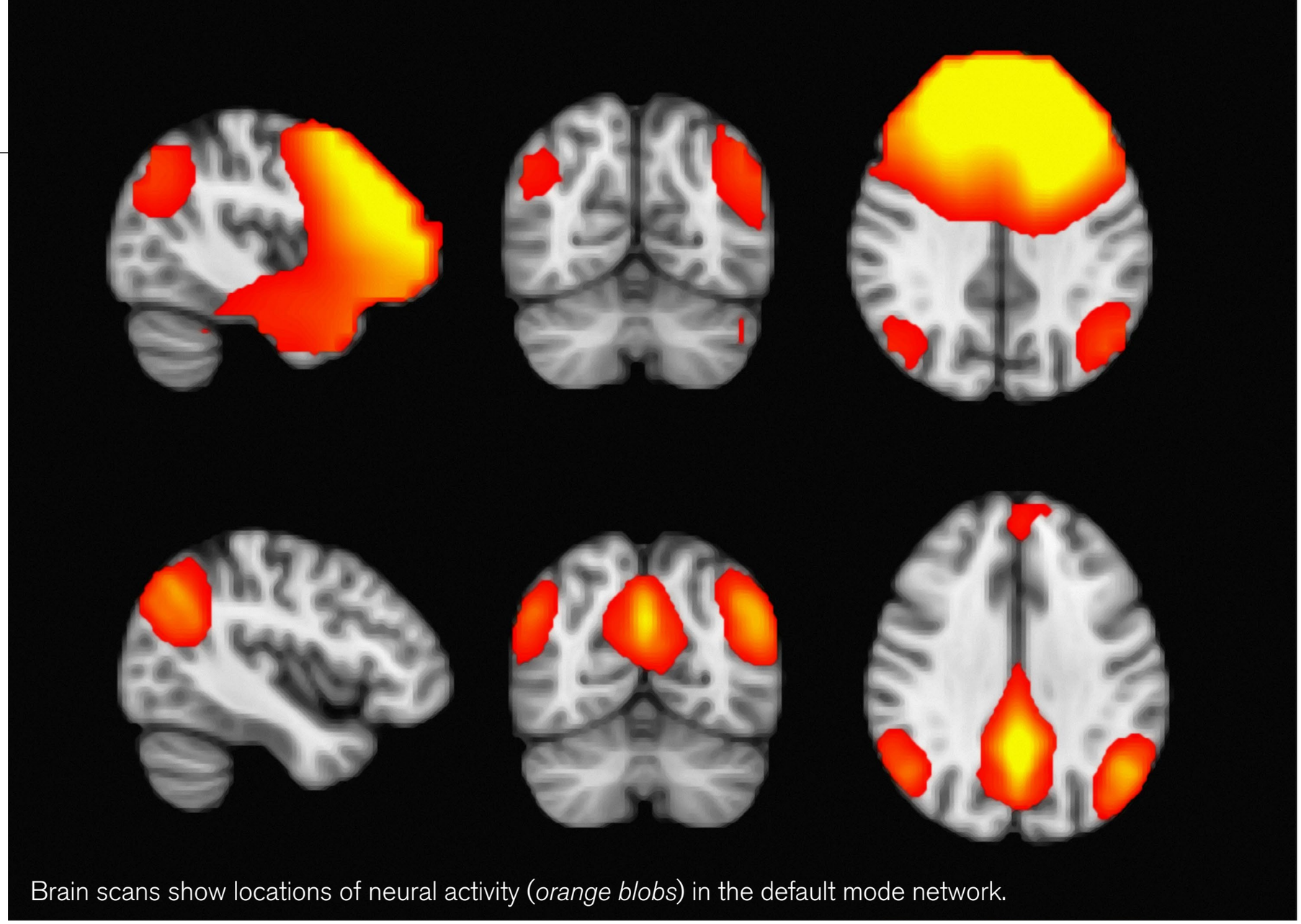
—Godfrey Pearlson

Constant Shifts between Mental States Mark a Signature of Consciousness

Both of two essential brain networks that switch roles—one is on when the other is off—shut down in unresponsive individuals

Imagine driving to work along the same route you take each day. Your mind wanders from one thing to the next: the staff meeting in the afternoon, plans for the weekend, a gift you need to buy for a friend. Suddenly a car cuts you off, and these thoughts immediately vanish—all of your attention focuses on maneuvering the steering wheel to avoid a collision. Although momentarily flustered, you—and your thoughts—return to the same wandering pattern a minute or two later.

As we go about our waking lives, our stream of consciousness typically cycles through many such alternations between introspection and outward attention throughout the day. It



Brain scans show locations of neural activity (*orange blobs*) in the default mode network.

JAMES KING-HOLMES AND HENRY LUCKHOO *SCIENCE SOURCE*

appears that the back-and-forth dance of these inward and outward mental states may be fundamental to brain function. A new study, led by neuroscientist Zirui Huang of the Center for Consciousness Science at the University of Michigan Medical School, suggests that the shifting balance between a network responsible for awareness of the environment and another responsible for awareness of the self may be a defining feature of consciousness.

The evidence comes from the absence of this pattern of brain activity in people rendered unresponsive, whether by anesthesia or by a neuropathological condition. As well as advancing our understanding of consciousness, the work could lead to the development of techniques to monitor it either prior to surgery or during the treatment of people with disorders of consciousness, such as vegetative or "locked-in" patients.

Over the past two decades neuroscientists have identified a network of brain regions responsible for various kinds of introspection from mind wandering to recollection and planning. The concept of "background" brain activity began drawing attention when neurologist Marcus Raichle and his colleagues at Washington University in St. Louis showed that the organ's energy consumption rose by less than 5 percent during a focused mental task, suggesting that it is never really idle. In 2001 Raichle coined the term "default mode" to describe this activity. Converging lines of evidence then led to the identification of regions constituting the default mode network (DMN), which underlies this self-directed cognition.

Activity in the DMN is "anticorrelated" with activity in the so-called dorsal attention network (DAT): the more active one of the two networks is, the less active the other tends to be. Activity in the DAT corresponds to attention directed outward, whereas the DMN underlies consciousness of self. This arrangement provides a potential account of our conscious experience in terms of a reciprocal balance between two opposing neural networks. "It's not an either-or thing; you're just tipping a balance," Raichle says. "We slide back and forth, but they're both there to some degree."

A portion of this research has remained controversial because of

a method used to clean noise from brain scan data that some researchers argue will always generate anti-correlated patterns as an artifact of data processing. In the study, published in March in *Science Advances,* Huang and his colleagues avoided the issue by adopting an approach that did not use this processing method. They instead took advantage of machine-learning techniques to classify brain-activation patterns into eight groups. Two of them corresponded to the DMN and DAT, and six were related to other known networks underlying brain functions: the sensory and motor network, the visual network, the ventral attention network, the frontoparietal network, and two networks representing cross-brain states of activation and deactivation.

To capture the brain activity, the team used a technique called resting-state functional magnetic resonance imaging (rsfMRI). Rather than averaging activity over long periods, which is typically done in rsfMRI studies to estimate how well connected regions are, the researchers wanted to investigate how moment-to-moment brain activation unfolds over time.

They showed that the organ rapidly cycles through different states corresponding to each of the eight networks, with some transitions being more probable than others—which Huang describes as a "temporal circuit." Notably, the brain passes through intermediate states between DMN and DAT activation rather than flipping instantaneously between the two extremes, which represents the highest-level cognitive processes.

The researchers scanned 98 participants who were either lying still but conscious or in an unresponsive state. The latter was caused by propofol or ketamine anesthesia or by a neuropathological condition known as unresponsive wakefulness syndrome—a vegetative condition resulting from brain injury. All these unresponsive states had one thing in common: the DMN and DAT were "isolated" from the constant flitting between networks of the temporal circuit, and they virtually never activated.

Each type of unresponsiveness varied in terms of the molecular mechanisms, neural circuits and experiences involved (those under ketamine anesthesia reported hallucinations, for instance). These observations could indicate that the absence of DMN-DAT activity is common to any form of diminished consciousness and that its presence may be a necessary feature of full consciousness. "What [the researchers are] suggesting here is: if you mess with that balance, you see a cost in consciousness," says Raichle, who was not involved in the study. "It's an interesting way to frame [DMN-DAT activity], and it's descriptive of our consciousness. But does it explain it? I'm not sure."

In another experiment, the researchers showed that playing a sound increased activation of the ventral attention network (which redirects our attention to unexpected stimuli) and suppressed activation of the DMN in conscious participants but not in unresponsive ones. A final control experiment assessed network activation in a database of brain scans of psychiatric patients. The scientists found no difference between this group and conscious participants in terms of DMN and DAT activity, showing that its loss is specific to reduced responsiveness, not to any form of disordered cognition.

There also were differences among the various unresponsive states. For instance, participants given ketamine more frequently entered cross-brain states of activation and deactivation. This pattern was also seen in scans of people with schizophrenia, suggesting that hyperactivity patterns may correspond to hallucinatory experiences common to both ketamine use and schizophrenia. "If all the processors share information everywhere in the brain, I guess you may lose the difference between yourself and the environment," Huang says. "Everything occurs at once, and you have distortions of your mental content."

The work could potentially be used to develop measures of consciousness for assessing the efficacy of treatments for disorders of consciousness or for online monitoring of anesthesia. "Once we see the two networks are diminished, we think individuals aren't aware of their environment," Huang says. Measures to gauge whether an individual is conscious or not could assist physicians in the surgical suite. He next plans to investigate the neural mechanisms that regulate these transitions in the temporal circuit making up these brain networks—an exploration of what orchestrates the dancing dynamics of conscious activity.

—Simon Makin

Longevity Gene May Protect against a Notorious Alzheimer's Risk Gene

Some nominally high-risk individuals may have a lower chance of developing dementia than once thought

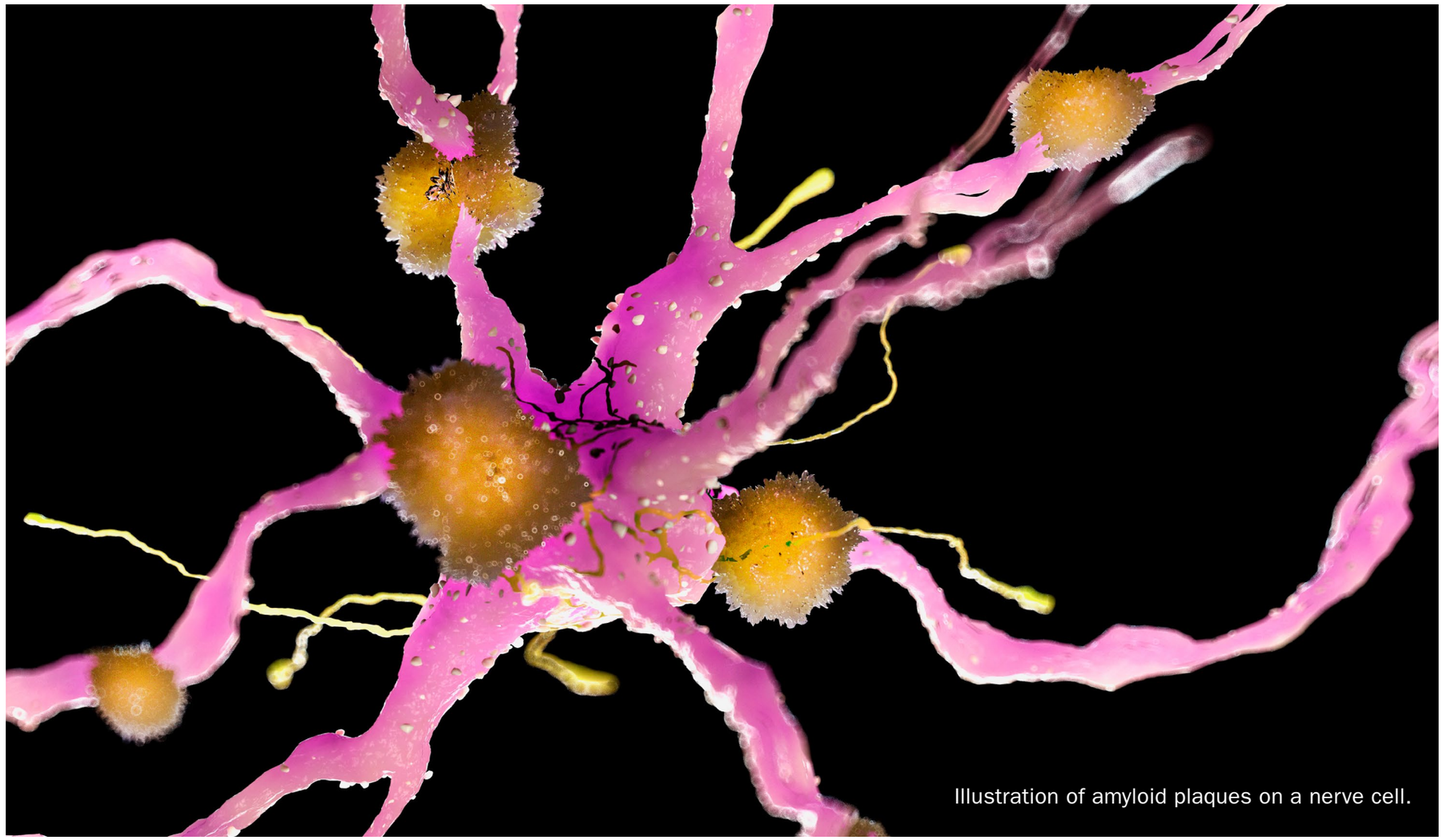


Illustration of amyloid plaques on a nerve cell.

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Consumer genetic tests can sometimes result in a terrible surprise appearing in the same report that divulges whether one has a cilantro aversion or wet or dry earwax. Test takers may receive the devastating news that they have a version of a gene—*apolipoprotein E* allele e4 (*APOE* e4)—that greatly increases their chances of getting Alzheimer's disease. The shock can be so great that some will seek solace in a support group to help them adjust to the possibility that they could run into cognitive problems beginning in their 50s or 60s.

One thing that makes the information so difficult to absorb is that there is no certainty about it. A person with one copy of the *APOE* e4 gene is more than three times as likely to wind up with Alzheimer's (one copy can be inherited from each parent). A hit of two copies increases the risk by 10 times or more. *APOE* e4 may also reduce the age of the disease's onset by up to a decade.

Still, not everyone who is an *APOE* e4 carrier will ultimately receive a diagnosis of Alzheimer's, the most common form of dementia. Given the ambiguities, scientists have long wondered whether other genes might counterbalance *APOE* e4's effects. A new paper may have found a candidate for just such a gene.

An analysis across multiple studies—with results from more than 20,000 individuals—found that *APOE* e4 carriers between the ages of 60 and 80 who also had a particular variant of a gene called *klotho* (named for Clotho, one of the Greek Fates, who spins the thread of life) were 30 percent less likely to receive an Alzheimer's diagnosis than carriers without it. People in their late 70s with a single copy of the *klotho* variant were also less apt to experience

the initial cognitive losses (mild cognitive impairments) that often precede an Alzheimer's diagnosis. Study participants with the relevant variant also had reduced signs of the hallmark clumps of beta-amyloid protein that turn up in the brain before symptoms arise.

The new study was published in April in *JAMA Neurology*. Two smaller investigations conducted in recent years had looked at whether *klotho,* a purported longevity gene, might provide some benefit for *APOE* e4 carriers. One of those studies affirmed that the gene variant did so, and the other suggested the opposite. Michael Greicius—senior author of the *JAMA Neurology* paper, an associate professor of neurology at Stanford University and medical director of the Stanford Center for Memory Disorders—had been considering doing research on *klotho* when he learned of the study with negative results. "I was kind of prepared to throw in the towel," he says. "But Michael Belloy [of Stanford], the first author on the [new] paper, had already gotten his teeth into this, thankfully. And we got all of these data sets about these *APOE* e4 interactions. And [they are] really quite strong and consistent."

The *klotho* variant studied by Greicius and his Stanford colleagues is not rare. Of the 10,000 subjects with at least one copy of *APOE* e4 examined by the researchers within the larger data compilation, there were 2,700 who carried the advantageous variant. *APOE* e4 is not uncommon either: the gene turns up in at least 15 to 20 percent of the population. It is present, however, in about half of the more than five million Alzheimer's cases in the U.S.

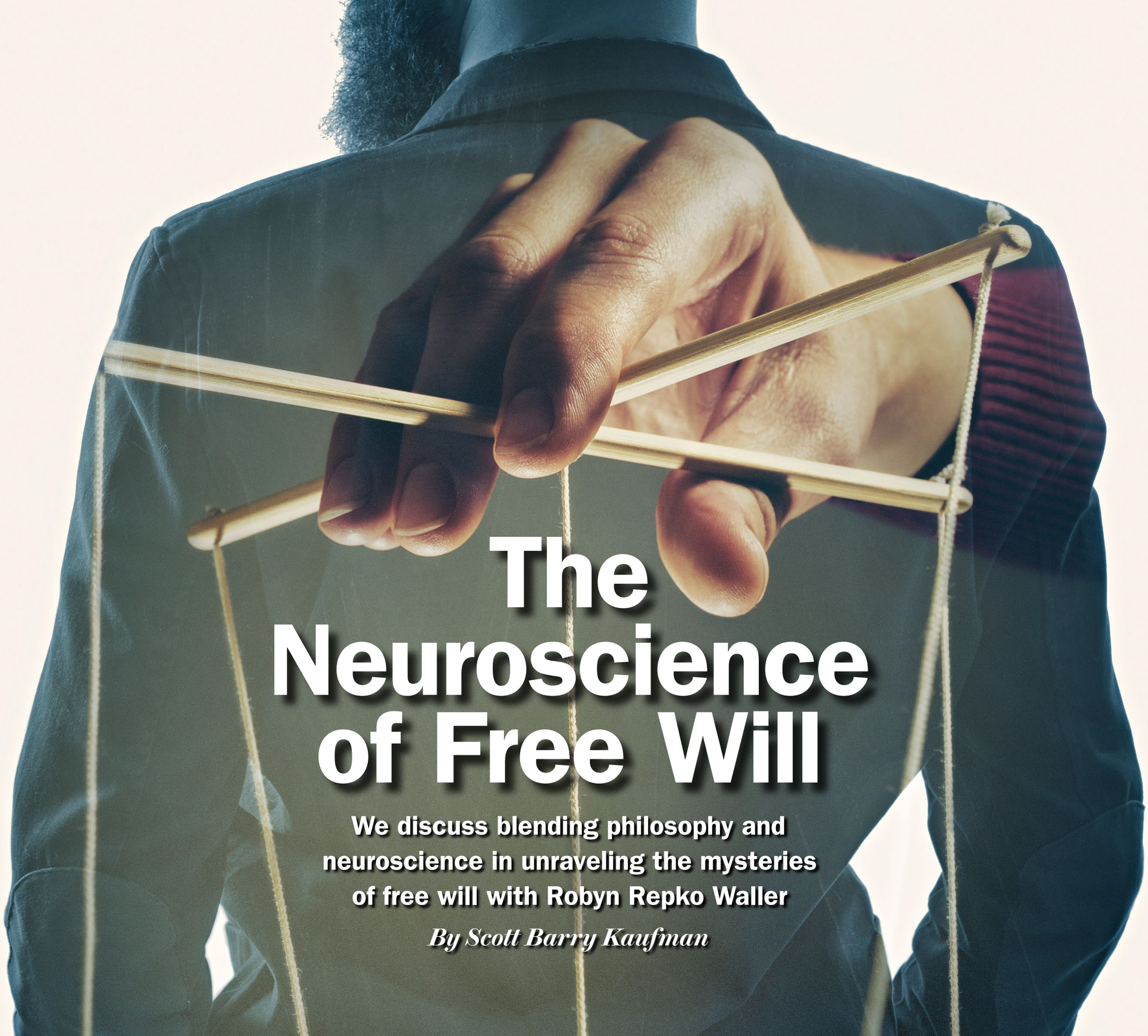
The new finding may add precision to the design of clinical trials and could potentially provide ideas for therapeutics. *APOE* e4 carriers are sometimes recruited for studies of drugs to prevent Alzheimer's because of the likelihood that they will get the disease. Excluding carriers who have the *klotho* variant might ensure that the pool of study participants is truly at high risk, as intended. Greicius and his colleagues' conclusions might also lead to new drug targets. "The whole pathway of proteins that involve *klotho* and its interaction with *APOE* e4 is now worth pursuing," he says.

Other scientists who were not involved with the research agree that the new results warrant taking a closer look at *klotho*. "I think these are important findings, and this genetic variant should be considered for incorporation into ongoing and future clinical research related to [Alzheimer's]," says David M. Holtzman, a professor and chair of the department of neurology at Washington University School of Medicine in St. Louis. He says that human-, animal- and cell-based research should now investigate why the *klotho* variant may partially protect *APOE* e4 carriers—and whether it might help early or late in the course of the disease. New studies must also focus on people who are not of northwestern European descent, as were those in the Stanford paper.

"I think this is an exciting finding," says Guojun Bu, who researches the *APOE* gene and is a professor and chair of the department of neuroscience at the Mayo Clinic. He points out that whereas *klotho* is considered a longevity gene, *APOE* e4 has been found to shorten life spans in humans—even when its link to Alzheimer's was discounted. But scientists have suspected that there are other genes that protect against its ill effects. In the case of *klotho,* a longevity gene may be countering an antilongevity one.

The Stanford study, Bu says, needs support from other research that examines *klotho* levels in both blood and cerebrospinal fluid and compares them with various measures of Alzheimer's biomarkers and pathology. Mice carrying a human version of the *APOE* e4 gene might also be used to look for relevant biological pathways that could explain these findings. And even some behavioral factors could be scrutinized. "As several lifestyle factors, including exercise and diet, are known to protect against *APOE* e4–related risk," Bu says, "it would also be interesting to examine whether they alter the levels of *klotho* as a potential underlying mechanism."

Dena Dubal, a *klotho* researcher who is an associate professor at the University of California, San Francisco, and an associate editor for *JAMA Neurology,* co-authored an accompanying commentary that called for further research on questions such as whether the gene could diminish *APOE* e4's disruption of cellular and brain-network activity. "The study carries exciting implications for future therapies," she says. "One wonders whether giving a boost of the *klotho* hormone itself, which drops in aging and Alzheimer's disease, could be a new treatment for individuals in preventing or treating Alzheimer's." —*Gary Stix*



The Neuroscience of Free Will

We discuss blending philosophy and neuroscience in unraveling the mysteries of free will with Robyn Repko Waller

By Scott Barry Kaufman

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Scott Barry Kaufman is a psychologist at Columbia University exploring intelligence, creativity, personality and well-being. In addition to writing the column Beautiful Minds for *Scientific American,* he hosts the Psychology Podcast and is author or editor of eight books, including *Wired to Create: Unraveling the Mysteries of the Creative Mind* (with Carolyn Gregoire) and *Ungifted: Intelligence Redefined.*

Who are you, and how did you become interested in free will?

I am an assistant professor of philosophy at Iona College, where I also serve as a faculty member for the Iona neuroscience program. I have previously worked in the Scientific and Philosophical Studies of Mind program at Franklin and Marshall College, as well as previous appointments as a lecturer at King's College London and University of Alabama. My recent and forthcoming publications focus on issues of autonomy in terms of philosophical accounts of free will, as well as how it intersects with neuroscience and psychiatry. One of the main questions I investigate is what neuroscience can tell us about meaningful agency (see here for my recent review of the topic as part of an extended review of research on agency, freedom and responsibility for the John Templeton Foundation).

I became interested in free will via an interdisciplinary route. As an undergraduate at Grinnell College, I majored in psychology with a strong emphasis on experimental psychology and clinical psychology. During my senior year at Grinnell I realized that I was fascinated by the theoretical issues operating in the background of the psychological studies that we read and conducted, especially issues of how the mind is related to the brain, prospects for the scientific study of consciousness and how humans as agents fit into a natural picture of the world. So I followed these interests to the study of philosophy of psychology and eventually found my way to the perfect fusion of these topics: the neuroscience of free will.

What is free will?

Free will seems to be a familiar feature of our everyday lives. Most of us believe that (at least at times) what we do is up to us to some extent—for instance, that I freely decided to take my job or that I am acting freely when I decide to go for a run this afternoon. Free will is not just that I move about in the world to achieve a goal but that I exercise meaningful control over what I decide to do. My decisions and actions are up to me in the sense that they are mine—a product of my values, desires, beliefs and intentions. I decided to take this job because I valued the institution's mission, or I believed that this job would be enriching or a good fit for me.

Correspondingly, it seems to me that at least at times I could have decided to and done something else than what I did. I decided to go for a run this afternoon, but no one made me, and I wasn't subject to any compulsion; I could have gone for a coffee instead, at least it seems to me.

Philosophers take these starting points and work to construct plausible accounts of free will. Broadly speaking, there is a lot of disagreement as to the right view of free will, but most philosophers believe that a person has free will if they have the ability to act freely and that this kind of control is linked to whether it would be appropriate to hold that person responsible (e.g., blame or praise them) for what they do. For instance, we don't typically hold people responsible for what they do if they were acting under severe threat or inner compulsion.

How do neuroscientists study free will?

There are plenty of sensational claims about the brain science of free will out there and lots of back-and-forth about whether or not science disproves free will (e.g., "My brain made me do it"). Given the strong link between free will and systems of moral and legal responsibility, like punishment, the stakes are high not just for our conception of human nature but also for our everyday practices that matter.

The current neuroscience of free will traces its lineage back to an influential experiment by Benjamin Libet and his colleagues. The majority of our actions begin with bodily movements, and most of us think that when we decide to move (e.g., decide to pick up my cup of tea), first I, the agent or person, decides and then I hand off control, so to speak, to the brain circuits for motor control to execute the action.

It was known since the 1960s from work by Kornhuber and Deecke that there is slow buildup of negative brain activity in the supplementary motor area (SMA) and pre-SMA measurable by electroencephalography (EEG) just prior to voluntary (i.e., movement initiated

by the participant) bodily movement. This brain activity, called the readiness potential (RP), was taken to be neural preparation to move for spontaneous movements and starts about a half-second before time of the movement (here).

So Libet and his fellow researchers ask, When does the agent appear in relation to the RP? The agent's decision has to be something measurable in the lab, so Libet asked participants to make movements (of the finger or wrist) at a time of their choosing and then report after the fact when they were first aware of their decision or urge to move using a modified clock (termed "W-time").

Libet found, contra the commonsense expectation, that the average reported time of first awareness of decision to move, W-time, occurred almost a third of a second after the start of the RP. So Libet (and select others since) concluded that the RP is the brain's unconscious decision to move with the agent's decision occurring later (here).

Libet took this as evidence that the conscious agent or self doesn't initiate, or kick off, preparation to act, the unconscious brain does. He argued that this result is representative of how all of our voluntary movements are produced, and if so, then the agent's conscious decision to act doesn't initiate the process leading to movement. But if the agent doesn't play this initiating role in acting, how can it be up to me how I act?

These results have worried a lot of folks and inspired a booming research enterprise in cognitive neuroscience and philosophy. One shouldn't jump to the depressing conclusion, though, that we don't act freely or don't really deserve any of the moral reactions others have to our actions; there is a healthy discussion on how the original Libet results can be interpreted as consistent with that picture of us humans as self-governing and free and moral persons.

W-time is taken to indicate moment of awareness of a decision. Can we capture "moments of conscious awareness" scientifically?

Since the initial publication of Libet and colleagues' study, worries about whether we could measure time of conscious awareness have been voiced. After all, we are talking here about the time frame of milliseconds. In these studies, all of the events measured prior to movement in the lab are happening within one second before the participant wiggles a finger or hand (now button presses are the preferred movement). Libet argued that W-time within a reasonable range was reliable, since we can see how accurately participants in the lab estimate the time of other events, such as skin shocks. The reliability of W-time has recently been challenged yet again with a new study that concludes that depending on the order in which participants complete certain tasks in the experiment, W-time can be strikingly different (i.e., there is an order effect; see here).

Other researchers are currently exploring alternative ways to measure a decision to move in the lab, including work by Parés-Pujolràs and co-authors, who have been using an online (i.e., premovement) measure of the agent's awareness of a decision to move (here).

In these studies, participants watch a continuous stream of letters on a computer while spontaneously pressing a button. Every now and then, though, the letters change color. When this happens participants are told to press the button just then if they were already aware of their preparing to press the button soon. These kinds of online measures of awareness may yet prove to be more reliable ways of getting at whether people have conscious intentions to act in the lab.

What's the latest work on neuroscience of free will?

Two of the hottest topics seem to be, first, what exactly the RP, that negative buildup of brain activity premovement, really signifies and, second, how we can make our voluntary actions in the lab more ecologically valid. As to the first, the past decade has seen researchers investigating if we have evidence that the RP really does stand for a decision to move or, alternatively, if the RP just is the brain's being biased to move in some way (say, left instead of right) without the commitment to do so.

Others test the possibility that the RP isn't really movement-specific activity at all (e.g., general cognitive preparation to perform a task voluntarily). Others, such as Schurger and colleagues, have argued via empirical studies that the RP is the neural signature that we pick up when our actions are generated by neural noise crossing some threshold (here). That possibility would be alarming, as then our actions, which we take to be undertaken by me for reasons, may really just be the passive result of fluctuating brain activity.

As to the second hot issue, researchers are now attempting to design tasks in the lab that are closer to the kind of decisions and action that we engage in daily. Libet argued that a simple movement like a wrist flex or button press could stand in for the more complex actions, as the RP has been shown to occur prior to more complex movements in the lab. Hence, we could give a unified explanation of the timing of events involving practical decisions and bodily movements.

But many, myself included, have voiced concern that when to press a button or whether to press a left or right button just isn't the right kind of action to stake a claim that we as agents don't initiate our actions via our conscious intentions to act. Hence, some of the ongoing work involves making the choice of which button to press or when to press it meaningful via rewards or penalties for skipping ahead or value-laden options, such as charity donations.*

And of course, there are plenty of neuroimaging tools at the disposal of cognitive neuroscientists. Some of the

most interesting replications and extensions of the Libet findings have been done using single-cell recording and functional MRI, among other technologies (see here and here, respectively). In fact, the neuroscience of free will has been and currently is the focus of some major research grants, such as the Big Questions in Free Will project (2010–2014; principal investigator [PI] Alfred Mele) and the Consciousness and Free Will project (2019; a collaboration across 17 PIs), each of which involves philosophers and numerous neuroscientific labs worldwide. From these grants I think we should expect further clarity on what's going on under the hood, so to speak, when we decide what to do and act voluntarily.

Are there any other results in neuroscience that tell us something intriguing about our agential control?

Yes, one of the aspects of our lives that seems the most undeniable is that we really do experience ourselves as in control of our movements and their effects in the world. There is a large body of work in cognitive neuroscience that focuses on this sense of agency via research on what's been termed intentional binding (for a recent academic review, see here).

Basically, if you ask participants in clever experimental setups to judge whether some event (e.g., icon moving on a computer screen) was the outcome of their agency or someone else's (i.e., "I did that" judgments), participants tend to misjudge an outcome to be a result of their own agency if it is a positive one and misjudge an outcome to be the result of another's agency if it is a negative one. That is, there is a self-serving bias to explicit-sense-of-agency judgments (for interesting results in this regard, see Wegner and Wheatley's 1999 paper here and other earlier work in psychology on attribution theory).

Cognitive neuroscientists have found a methodology to study our sense that we are in control of our actions and actional outcomes without surveying participants' explicit "I did that" judgments. Instead experimenters ask participants to judge the time of various events, including their movements (e.g., a button press) and the sensory outcomes of those movements (e.g., a beep following the button press). What researchers have found is that if you voluntarily press a button and hear a tone as a consequence, you are going to judge that the time of the movement and the time of the tone are much closer together in perceived space than if you are caused to move (via neural stimulation) and hear a tone as a consequence.

In other words, the perceived time of the action and the tone "bind together" in perceptual space when you act voluntarily as opposed to when you are caused to move or simply judge the time of events without acting (here). What's intriguing about this research on agency, then, is that our perceptual judgments about the world seem to distinguish when we act from when something is done to us. Research work on intentional binding has tackled more ecologically valid issues of sense of agency when acting under emotional distress, due to coercion, and in the face of options.*

*Neuroscientists working on more representative kinds of decisions and/or sense of agency in more ecologically valid contexts include researchers in the UCL Action and Body Lab at University College London and the Brain Institute at Chapman University, among others.

The Right Way to Talk across Divides

"Conversational receptiveness" can be learned

By Francesca Gino, Julia Minson and Mike Yeomans

JOHN M. LUND GETTY IMAGES

Francesca Gino is an award-winning behavioral scientist and Tandon Family Professor of Business Administration at Harvard Business School. She is author of *Rebel Talent: Why It Pays to Break the Rules at Work and in Life,* as well as *Sidetracked: Why Our Decisions Get Derailed, and How We Can Stick to the Plan.*
Julia Minson is an associate professor of public policy at the John F. Kennedy School of Government at Harvard University. She is a social psychologist with research interests in conflict, negotiations, and judgment and decision-making.
Mike Yeomans is currently a postdoctoral fellow at Harvard Business School and will be starting as an assistant professor at Imperial College Business School this summer. In his research, he uses natural-language processing to study decision-making in conversation.

IN THE WAKE OF THE 2016 U.S. PRESIDENTIAL ELECTION, three longtime friends—author David Blankenhorn, family therapist Bill Doherty and family research scholar David Lapp—were bothered by the animosity that seemed to have grown exponentially between Democrats and Republicans. The divide went beyond differing opinions on candidates and policies, they believed. Rather liberals and conservatives increasingly seemed to view each other as inherently immoral, unintelligent and malicious. Fewer and fewer Americans seemed interested in constructively engaging with the other side.

The three had an idea inspired by Doherty's expertise in divorce and family conflict as a professor of family social science and program director of the Minnesota Couples on the Brink project at the University of Minnesota. What if they could apply some of the same techniques and theories used in family therapy to try to heal the American "family"? And so they got to work, establishing a nonprofit organization called Better Angels (recently renamed Braver Angels) and adapting workshops and debates from the realm of therapy to cultivate goodwill between liberals and conservatives. The three were inspired by Abraham Lincoln's warning of the dangers of disunity in his first inaugural address. We can heal divisions by listening to the "better angels of our nature," the president told a country on the brink of civil war.

In Braver Angels workshops, Democrats and Republicans come together to learn how to have more productive conversations. An exercise called "Fishbowl" involves members of one political party sitting in a circle with those of the other group sitting around them. The outside group sits quietly and listens to the inside group answer a set of questions, such as "Why do you think your side's policies or candidates are good for the country?" or "What is an experience from your life that had a big impact on your political views?"

After each side has had the opportunity to answer and listen, the moderators bring the larger group together for conversations about what everyone learned. "People tend to say, 'Before the workshop, I thought my side was fractured and disorganized and that the other side was monolithic and effectively mobilized,'" Blankenhorn says. "They come to see that both sides can be incredibly diverse and disorganized." Despite their strong beliefs and views, participants in the workshops change their attitude toward one another for the better, data suggest.

U.S. polarization extends beyond politics, of course. Disagreement is a key feature of social life, permeating organizations, families, friendships and crisis response. We regularly find ourselves engaging with people whose fundamental beliefs and core values differ from our own. One common response is to try to convince them to abandon their point of view in favor of ours. But that approach can backfire, leading to unproductive conflict. The good news is that people who disagree passionately on political and social issues can be trained, fairly easily, to have productive interactions.

Our research focuses on improving what we call conversational receptiveness—the extent to which parties in disagreement can communicate their willingness to engage with each other's views. Conversational receptiveness involves using language that signals that a person is truly interested in another's perspective. When individuals appear receptive in conversation, others find their

arguments to be more persuasive, our work shows. In addition, receptive language is contagious: it makes those one disagrees with more receptive in return. People also like others more and are more interested in partnering with them when they seem receptive. Disagreements that might have spiraled into heated conflicts instead lead to conflict resolution.

We identified the features of receptive language by asking thousands of individuals to write responses to political statements with which they disagreed. We then had thousands of others evaluate each response in terms of how engaged, receptive and open-minded the writer seemed.

People know receptiveness when they see it. Our raters were in general agreement about which writers demonstrated receptiveness and which did not. Humans, however, are not able to pinpoint which words and phrases make a piece of text feel more or less receptive. So we developed an algorithm that could quickly analyze thousands of lines of text and identify specific words and phrases correlated with receptiveness. The algorithm allowed us to pick out the signal from the noise.

First we found that words of acknowledgment signal receptiveness. Acknowledging the views of someone you disagree with by saying "I understand that …" or "I believe what you're saying is …" shows that you are engaged in the conversation. Hedging—indicating some uncertainty about the claim you are about to make—is also a sign of receptiveness. For example, "Going forward with this decision might increase market share" expresses more uncertainty, sounds less dogmatic and is thus better received than "Going forward with this decision will undoubtedly increase our market share."

Another feature of receptive language is the use of positive rather than negative terms. "It is helpful to consider the benefits of investing fewer resources into an existing project" seems more receptive than "We should not invest any more resources into an existing project." Finally, words such as "because" and "therefore" can set an argumentative or condescending tone in conversation. Individuals signal receptiveness when they avoid them.

After we had identified features of language that suggest receptiveness, we conducted studies in which we trained people to be more receptive and then observed whether others viewed them as such. Specifically, we gave some participants five minutes of training in using receptive language and then had them write a response to an essay written by a person they disagreed with on a given set of issues (such as policing and minority suspects or sexual assaults on college campuses). Participants in a control group wrote their response using their natural conversational style.

We assigned other participants to respond to one of these pieces of writing—specifically, to an essay by someone whose views they disagreed with. Those trained in receptiveness communication were more successful at persuading readers to shift their beliefs on important social issues, the results showed. They were also more sought-after partners for future conversations and were seen as having better judgment.

In another study, we leveraged data from a realm where disagreement is common: Wikipedia. We identified threads containing personal attacks in the talk pages for popular articles, as well as threads for the same article (with a similar length and date) that did not contain a personal attack. These data allowed us to examine the effect of receptiveness in the editorial process of correcting Wikipedia articles. We found that editors who were more receptive were less likely to incur personal attacks during editorial discussions. Communicating receptively prompted others to reciprocate by being receptive themselves.

Consistent with the lessons emerging from Braver Angels workshops, this research shows that through conversational receptiveness, we can begin to bridge our divides, whether in politics or family life or at work.

Roots *of* Mental Illness

Researchers are beginning to untangle the common biology that links supposedly distinct psychiatric conditions

By Michael Marshall

PAWEŁ JOŃCA

Michael Marshall is a freelance writer based in Devon, England.

IN 2018 PSYCHIATRIST OLEGUER PLANA-RIPOLL WAS WRESTLING WITH a puzzling fact about mental disorders. He knew that many individuals have multiple conditions—anxiety and depression, say, or schizophrenia and bipolar disorder. He wanted to know how common it was to have more than one diagnosis, so he got his hands on a database containing the medical details of around 5.9 million Danish citizens.

He was taken aback by what he found. Every single mental disorder predisposed the patient to every other mental disorder—no matter how distinct the symptoms. "We knew that comorbidity was important, but we didn't expect to find associations for all pairs," says Plana-Ripoll, who is based at Aarhus University in Denmark.

The study tackles a fundamental question that has bothered researchers for more than a century: What are the roots of mental illness?

In the hope of finding an answer, scientists have piled up an enormous amount of data over the past decade through studies of genes, brain activity and neuroanatomy. They have found evidence that many of the same genes underlie seemingly distinct disorders, such as schizophrenia and autism, and that changes in the brain's decision-making systems could be involved in many conditions.

Researchers are also drastically rethinking theories of how our brains go wrong. The idea that mental illness can be classified into distinct, discrete categories such as anxiety and psychosis has been disproved to a large extent. Instead disorders shade into each other, and there are no hard dividing lines—as Plana-Ripoll's study so clearly demonstrated.

Now researchers are trying to understand the biology that underlies this spectrum of psychopathology.

They have a few theories. Perhaps there are several dimensions of mental illness—so depending on how people score on each dimension, they might be more prone to some disorders than to others. An alternative, more radical idea is that a single factor makes people prone to mental illness in general, and which disorder they develop is then determined by other factors. Both ideas are being taken seriously, although the concept of multiple dimensions is more widely accepted by researchers.

The details are still fuzzy, but most psychiatrists agree that one thing is clear: the old system of categorizing mental disorders into neat boxes does not work. They are also hopeful that in the long run replacing this framework with one that is grounded in biology will lead to new drugs and treatments. Researchers aim to reveal, for instance, the key genes, brain regions and neurological processes involved in psychopathology and target them with therapies. Although it might take a while to get there, says Steven Hyman of the Broad Institute of M.I.T. and Harvard in Cambridge, Mass., "I am long-term optimistic if the field really does its work."

A SMORGASBORD OF DISORDERS

The most immediate challenge is working out how to diagnose people. Since the 1950s psychiatrists have used an exhaustive volume called the *Diagnostic and Statistical Manual of Mental Disorders,* currently in its fifth edition. It lists all the recognized disorders, from autism and obsessive-compulsive disorder to depression, anxiety and schizophrenia. Each is defined by symptoms. The inherent assumption is that each disorder is distinct and arises for different reasons.

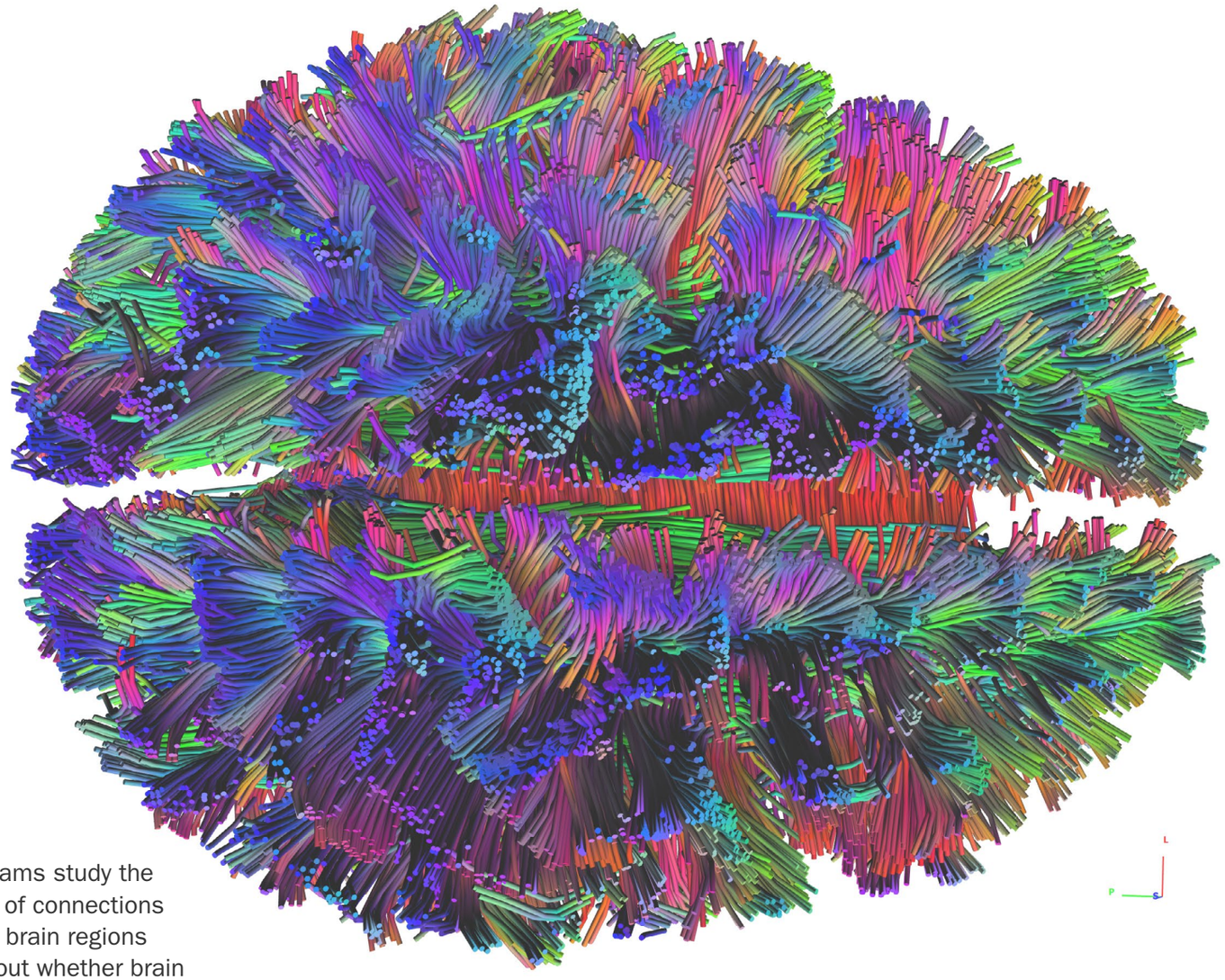
Even before the *DSM-5* was published in 2013, however, many researchers argued that this approach was flawed. "Any clinician could have told you that patients had not read the *DSM* and didn't conform to the *DSM,*" says Hyman, who helped to draft the manual's fifth edition.

Few patients fit into each neat set of criteria. Instead people often have a mix of symptoms from different disorders. Even if someone has a fairly clear diagnosis of depression, they often have symptoms of another disorder such as anxiety. "If you have one disorder, you're much more likely to have another," says Ted Satterthwaite, a neuropsychiatrist at the University of Pennsylvania.

This situation implies that the way clinicians have partitioned mental disorders is wrong. Psychiatrists have tried to solve this by splitting disorders into ever finer

subtypes. “If you look at the way the *DSM* has evolved over time, the book gets thicker and thicker,” Satterthwaite says. But the problem persists—the subtypes are still a poor reflection of the clusters of symptoms that many patients have.

As a result, the world’s largest funder of mental health science, the U.S. National Institute of Mental Health, changed the way it funded research. Beginning in 2011, it began demanding more studies of the biological basis of disorders, instead of their symptoms, under a program called the Research Domain Criteria. There has since been an explosion of research into the biological basis of psychopathology, with studies focusing on genetics and neuroanatomy, among other fields. But if researchers hoped to demystify psychopathology, they still have a long way to go: the key finding has been just how complex psychopathology really is.



Some teams study the strength of connections between brain regions to work out whether brain function correlates with particular diagnoses.

CONTROVERSIAL CLUSTERS

Clinically, the evidence that symptoms cut across disorders—or that people frequently have more than one disorder—has only grown stronger. For this reason, although individual symptoms such as mood alterations or impairments in reasoning can be diagnosed reliably, assigning patients to an overall diagnosis such as bipolar disorder is difficult.

Even seemingly separate disorders are linked. In 2008 geneticist Angelica Ronald, then at King’s College London Institute of Psychiatry, and her colleagues found that autism and attention deficit hyperactivity disorder (ADHD) overlapped. “At the time you weren’t allowed to be diagnosed with both conditions,” Ronald says; this was because of a rule in an earlier version of the *DSM*. But she and her team found that traits for autism and ADHD were strongly correlated and partially under genetic control.

Furthermore, there seem to be clusters of symptoms that cross the boundaries of disorders. A 2018 study examined people who had been diagnosed with major depression, panic disorder or post-traumatic stress disorder (PTSD). The volunteers were assessed on the basis of their symptoms, cognitive performance and brain activity. The researchers found that the participants fell into six groups characterized by distinct moods such as tension and melancholia. The groups cut across the three diagnostic categories as if they were not there.

Many now agree that the diagnostic categories are wrong. The question is, With biology as their guide, what should psychiatric diagnosis and treatment look like instead?

MULTIPLE DIMENSIONS

One prominent model is that there are a number of neuropsychological traits or dimensions that vary in every person. Each trait determines our susceptibility to certain kinds of disorder. For example, someone might be prone to mood disorders such as anxiety but not

MATTHEW CIESLAK, TED SATTERTHWAITE AND DANIELLE S. BASSETT

to thought disorders such as schizophrenia.

This is similar to the way psychologists think about personality. In one model, five personality traits, such as conscientiousness and neuroticism, describe most of the variation in human personalities.

Some psychiatrists are already trying to reimagine their discipline with dimensions in mind. In the early 2010s there was a push to eliminate disorder categories from the *DSM-5* in favor of a "dimensional" approach based on individual symptoms. This attempt failed—partly because health care funding and patient care have been built up around the *DSM*'s categories. Other catalogues of disorders, however, have shifted toward dimensionality. In 2019 the World Health Assembly endorsed the latest International Classification of Diseases (called ICD-11), in which some psychopathologies are newly broken down using dimensional symptoms rather than categories.

The challenge for the dimensionality hypothesis is obvious: How many dimensions are there, and what are they? Satterthwaite calls this "a very large problem."

One popular theory, supported by many studies over the past decade, argues for just two dimensions. The first includes all internalizing disorders, such as depression, in which the primary symptoms affect a person's internal state. This is contrasted with externalizing disorders, such as hyperactivity and antisocial behavior, in which a person's response to the world is affected. Studies suggest that if someone has been diagnosed with two or more disorders, they are most likely from the same category.

But studies combining large amounts of brain-imaging data with machine learning have turned up different numbers—even in studies done by the same lab. Last year Satterthwaite and his group published a study of 1,141 young people who had internalizing symptoms, which showed that they could be split into two groups on the basis of their brain structure and function. In 2018 Satterthwaite led a similar study and identified four dimensions, each associated with a distinct pattern of brain connectivity.

Ultimately a future version of the *DSM* could have chapters devoted to each dimension, Hyman says. They could list the disorders that cluster within each, as well as their symptoms and any biomarkers derived from the underlying physiology and genetics. Two people who had similar symptoms but different sets of mutations or neuroanatomical alterations could then be diagnosed and treated differently.

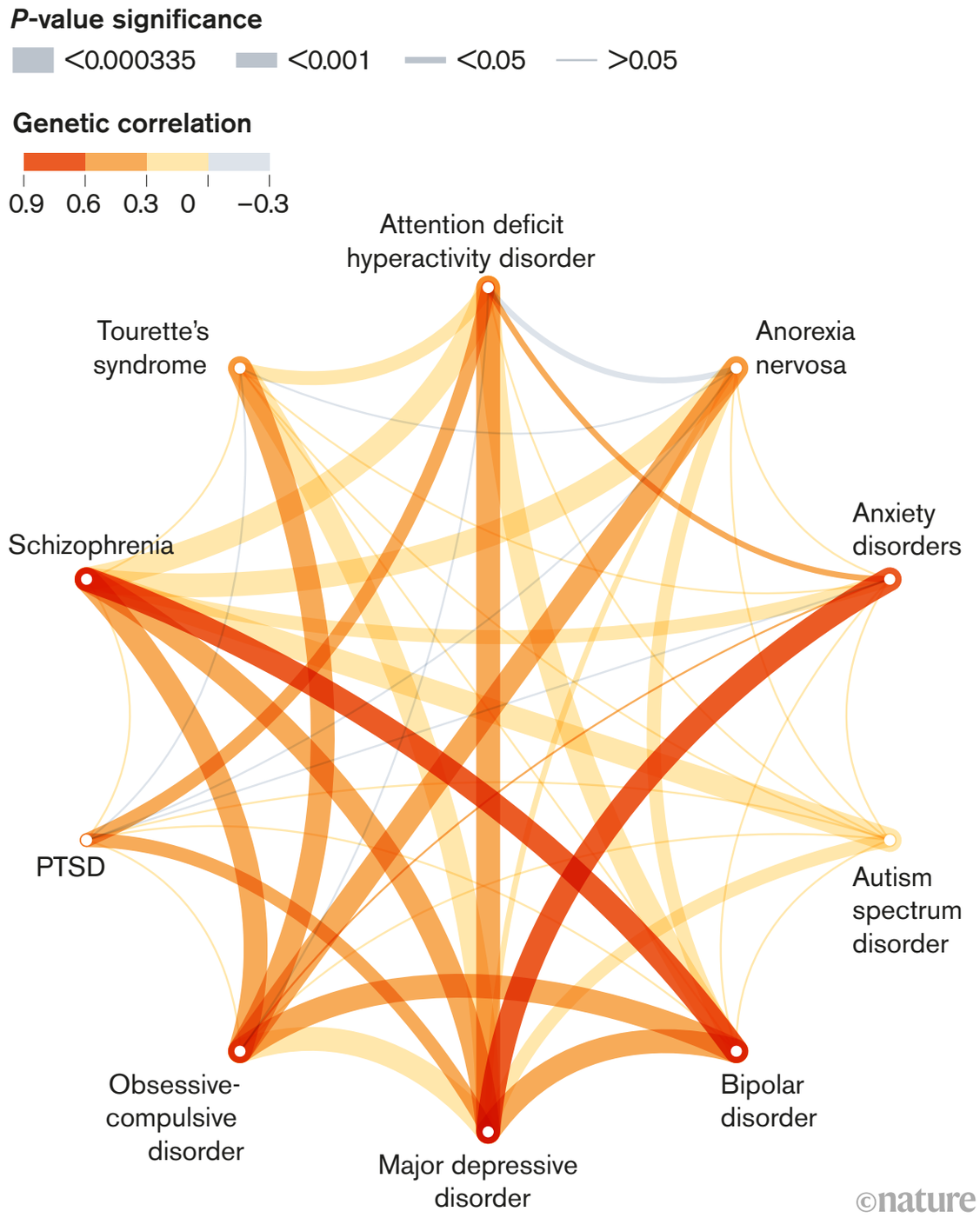
IN THE GENES

One pillar of this future approach is a better understanding of the genetics of mental illness. In the past decade studies of psychopathological genetics have become large enough to draw robust conclusions.

The studies reveal that no individual gene contributes much to the risk of a psychopathology; instead hundreds of genes each have a small effect. A 2009 study found that thousands of gene variants were risk factors for schizophrenia. Many were also associated with bipolar disorder, suggest-

MENTAL MAP

Similar genetic variants seem to underlie a number of psychiatric disorders. In one study of 200,000 people, schizophrenia was significantly correlated with most other disorders. By contrast, some disorders such as post-traumatic stress disorder (PTSD) showed only weak correlations to other conditions.



ing that some genes contribute to both disorders.

This is not to say that the same genes are involved in all brain disorders: far from it. A team led by geneticist Benjamin Neale of Massachusetts General Hospital in Boston and psychiatrist Aiden Corvin of Trinity College Dublin found in 2018 that neurological disorders such as epilepsy and multiple sclerosis are genetically distinct from psychiatric disorders such as schizophrenia and depression.

These studies all looked at common variants, which are the easiest to detect. Some recent studies focused instead on extremely rare variants, which do suggest genetic differences between disorders. A study of more than 12,000 people found that individuals with schizophrenia had an unusually high rate of ultrarare mutations—and that these mutations were often unique to one individual.

The result is a mess. It is difficult to predict which risk factors cut across conditions. "Some of them are quite broadly shared across psychopathology," Neale says, "whereas some are a bit more specific to one or a handful of forms of psychopathology."

THE *P* FACTOR

Some psychiatrists have put forward a radical hypothesis that they hope will allow them to make sense of the chaos. If disorders share symptoms, or co-occur, and if many genes are implicated in multiple disorders, then maybe there is a single factor that predisposes people to psychopathology.

The idea was first proposed in 2012 by public health specialist Benjamin Lahey of the University of Chicago. Lahey and his colleagues studied symptoms in 11 disorders. They used statistics to examine whether the pattern could best be explained by three distinct dimensions or by those three together with a "general" predisposition. The model worked better if the general factor was included.

The following year the hypothesis received more support—and a catchy name—from husband-and-wife psychologists Avshalom Caspi and Terrie Moffitt of Duke University. They used data from a long-term study of 1,037 people and found that most of the variation in symptoms could be explained by a single factor. Caspi and Moffitt called this the *p* factor. Since 2013 multiple studies have replicated their core finding.

"I think it's a time for much more empirical research rather than grand theorization."
—Steven Hyman

Caspi and Moffitt were clear that the *p* factor could not explain everything, and they made no guesses about its underlying biology, speculating only that a set of genes might mediate it. Others have proposed that the *p* factor is a general predisposition to psychopathology but that other factors—stressful experiences or other gene alterations—nudge a person toward different symptoms. But if it is real, it has a startling implication: there could be a single therapeutic target for psychiatric disorders.

There are already hints that generalized treatments could work just as well as targeted therapies. A 2017 study randomly assigned people with anxiety disorders such as panic disorder and obsessive-compulsive disorder to receive either a therapy for their specific disorder or a generalized approach. Both therapies worked equally well.

Finding a physiological basis for the *p* factor would be the first step toward therapies based on it, but only in the past few years have researchers found hints of it in genetic and neuroanatomical data. One study of the genetics of psychopathology in a U.K. population, for instance, identified a genetic *p* factor—a set of genes in which there were variations that contributed to the risk of psychopathology.

Meanwhile other groups have searched for a neuroanatomical change that occurs in multiple psychopathologies. The results are intriguing but contradictory.

One study of six psychopathologies found that the brain's gray matter shrank in three regions involved in processing emotions: the dorsal anterior cingulate, the right insula and the left insula. But subsequent studies by Adrienne Romer, a clinical psychologist now at Harvard Medical School and McLean Hospital in Belmont, Mass., identified a totally different trio of regions with roles that include managing basic bodily functions and movement—the pons, the cerebellum and part of the cortex. One key to making sense of this might be to focus on the brain's executive function: the ability to regulate behavior by planning, paying attention and resisting temptation, which relies on many brain regions. Romer and Satterthwaite have independently found disruptions in executive function in a range of psychopathologies—the suspicion being that these disruptions could underlie the *p* factor.

Most scientists agree that what is needed is more data, and many remain unconvinced by such simple explanations. "I'm a little less certain that that's how it's going to play out," Neale says. At the genetic level at least, he says, there are many disorders, such as PTSD and generalized anxiety disorder, that remain poorly understood.

All such sweeping hypotheses are premature, Hyman says. "I think it's a time for much more empirical research rather than grand theorization."

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Steve Taylor is a senior lecturer in psychology at Leeds Beckett University in England. He is author of *Spiritual Science: Why Science Needs Spirituality to Make Sense of the World*.

MENTAL HEALTH

The Coronavirus and Post-traumatic Growth

Surviving an awful experience can lead to some surprisingly positive psychological effects in many people

URSA HOOGLE GETTY IMAGES

On March 6, 1987, a ferry traveling from England to Belgium capsized, causing the death of 193 people. In the months after the disaster, many of the approximately 300 survivors suffered symptoms of post-traumatic stress disorder (PTSD), including upsetting dreams; anxiety; emotional detachment and numbness; and difficulties with sleep and concentration.

In time, however, some of the survivors reported some surprising positive effects. Three years after the disaster, psychologist Stephen Joseph, then a Ph.D. student, carried out a survey and found that although PTSD was still common (albeit with diminished symptoms), 43 percent of the survivors reported that their view of life had changed for the better. They reported that they no longer took life for granted, that they valued

their relationships more, that they lived each day to the fullest, that they felt more experienced about life, and so on.

This was one of the first studies of a concept that has become very important in psychology in recent years: post-traumatic growth.

Post-traumatic growth (or PTG) is the idea that in the long run, traumatic events and experiences—such as illness, accidents, bereavement, addiction and divorce—can have beneficial effects. Often, after the initial shock and pain of a traumatic situation have faded away, people report feeling more appreciative of their lives and sensing a new inner strength and confidence. They feel that their relationships are more intimate and authentic and that they have a new sense of meaning and purpose. They often become less materialistic and more altruistic, more concerned with the well-being of others than with their own success and status. They develop a more philosophical or spiritual attitude to life with—in the words of Richard Tedeschi and Lawrence Calhoun, two of the pioneers of the theory of PTG—a "deeper level of awareness."

Overall it appears that nearly half of people who experience such traumatic events are likely to experience PTG in the aftermath.

Post-traumatic growth (or PTG) is the idea that in the long run, traumatic events and experiences—such as illness, accidents, bereavement, addiction and divorce—can have beneficial effects.

POST-TRAUMATIC TRANSFORMATION

Over the past 10 years or so, my own research has focused on what I call post-traumatic transformation. I have found that psychological turmoil and trauma may bring about not simply growth but a dramatic transformation. After a period of intense suffering (such as when one receives a diagnosis of cancer or experiences a long period of depression or addiction), a person may undergo a sudden shift of identity.

All of a sudden they feel like a different person inhabiting the same body with heightened sensory awareness, an increased sense of compassion and connection, and new values or goals. For example, a woman who experienced post-traumatic transformation after the death of her daughter told me that she felt like she had broken through "to another state. I've moved up to another level of awareness which I know is going to stay with me."

As I showed in my book *The Leap,* many people can specify a particular moment at which transformation occurred, often at the moment when they shifted into an attitude of acceptance of their predicament. For example, a man told me how, as an alcoholic undergoing the Alcoholics Anonymous recovery process, he experienced transformation at the moment when he "handed over" his problem. Another person had become severely disabled and underwent a shift at the point when he heard an inner voice say, "Let go, man, let go. Look at how you're holding on. What do you think life's telling you?" A woman went through a period of intense postnatal depression, entering into a psychotic state that led to four nights without sleep. In the midst of this turmoil, she had an argument with her husband, which suddenly triggered what she described as "feelings of such perfect joy and peace. I remember thinking afterward, 'So that's what I'm supposed to feel like!' Within that one instant, you are forever changed."

TRANSFORMATION OF COMMUNITIES

PTG (and post-traumatic transformation) can happen to groups and communities, as well as to individuals.

When a crisis occurs in a community (such as a war or a natural disaster), people often react by becoming more interconnected. They become friendlier, more cooperative and altruistic. People feel a common sense of purpose, and a spirit of cooperation begins to replace normal competitiveness. For the community, this often equates to a kind of PTG. The whole community shifts into a higher level of integration. It is as if rather than existing as isolated individuals, people fuse together into a whole. One study showed evi-

dence of collective PTG after natural disasters such as earthquakes and floods. In these situations, people developed communal coping strategies and had more collective gatherings.

I witnessed this phenomenon about three years ago following a terrorist attack in my home city of Manchester, England, in which 23 people, including the bomber, died when a man detonated a homemade explosive device at an arena. In the days and weeks after the attack, there was a strong sense of togetherness. People were talking more and helping one another more. Different ethnic groups were interacting more. Barriers and boundaries seemed to fall away. There was a sense of trust and empathy in the community. Of course, the sense of togetherness began to wane, but I do not think it has faded away completely. I think the event brought about a new kind of integration that is still present today, at least to a degree.

PTG AND THE CORONAVIRUS

This does not always happen, of course. Sometimes crises can have the opposite effect and lead to a kind of post-traumatic stress in which social bonds fall away and people become more selfish and individualistic. Perhaps communal PTG following a crisis is roughly as common as individual PTG.

My feeling, however, is that PTG will be one of the aftereffects of the coronavirus epidemic. Many of us will surely undergo individual growth (and perhaps even transformation). In the midst of the suffering and challenge of our present predicament, we may develop a heightened sense of appreciation, more authentic relationships, and a new sense of resilience and confidence. We may slow down and learn to live in the present rather than filling our lives with incessant activity and constantly rushing into the future.

But we will surely undergo some degree of communal growth as well. In the U.K., there are signs that this is happening already. People appear to be valuing each other more, appreciating the different contributions we are making and letting go of grievances and disagreements. Despite social distancing, we appear to be feeling more empathy for each other and acting more altruistically. In Manchester, I can sense the same spirit of togetherness that arose after the terrorist attack.

But perhaps PTG will occur at an even higher level, too—that is, at a global level. One of the most salient aspects of the virus is its global nature. It reminds us that we are one species and that differences of nationality, ethnicity and religion are meaningless labels. We are all in this together, and we will overcome the crisis only through cooperation. Conflict and competition will only lead to more suffering and discord.

During a time of increasing individualism in which many governments have been taken over by narcissistic and sociopathic autocrats intent on asserting their own individual power and identity, PTG up to the global level is precisely what the world needs.

When this is all over, we may find that we are stronger and closer to one another than before.

Patricia Izbicki is a Ph.D. candidate and a research and teaching assistant in the Interdepartmental Neuroscience Program at Iowa State University.

ARTS & CULTURE

Your Brain Will Thank You for Being a Musician

Here are five reasons why

ELI ASENOVA GETTY IMAGES

Music, like mathematics, is a universal language. We can communicate a variety of emotions and themes that touch the very depths of our soul with the vigorous movement of air through a trumpet or the tender touch of fingers on a keyboard. Musicians (both professional and amateur) are at a unique advantage because they have the opportunity not only to communicate universally but also to improve their brain health. Your brain will thank you for being a musician for five reasons:

1. Music training promotes neuroplasticity. Neuroplasticity is the brain's ability to change throughout life. The Hebbian principle (neurons that fire together wire together) is what underlies it. The more you engage in any activity, the more consistently neurons are firing together, which results in stronger connections. What is unique about music training is its capacity to induce neuroplastic changes in *all* areas of the brain. You use your occipital lobe to read and interpret pitches and rhythm; your temporal lobe to process sound; your frontal lobe to attend to the music, inhibit irrelevant distractions and remember what you just played; and your parietal lobe to integrate all of the incoming sensory information.

2. Music training improves cognitive abilities. Studies have shown that music training improves cognitive abilities (e.g., working memory, attention and inhibition) across our life span. This has been shown with both short-term and long-term music training. Because playing an instrument requires many different areas of the brain, it strengthens a

variety of neuronal connections. This allows for an increase in signal efficiency (that is, how quickly neurons communicate with one another across the brain), which may be why musicians may perform better in cognitive tasks than nonmusicians.

3. Music training may promote healthy aging of the brain. Studies show that musicians have an advantage in maintaining their cognitive abilities during the aging process. This includes tasks that involve executive functioning and short-term memory. Older musicians have other advantages as well. One study showed that the ability to filter out irrelevant environmental stimuli (that is, focus) was more intact in older musicians, and their brain activity reflected this advantage. Another has shown that older musicians are able to hear more clearly in the presence of background noise. And there are benefits from both long-term and short-term training.

4. Music training is beneficial for overall health. A recent study has shown that group musical activities are potential ways to maintain physical and psychological health. For example, a lowered risk of dementia has been associated with playing musical instruments. Other studies have shown that playing keyboard and drums could improve people's fine and gross motor skills after a stroke. These benefits were accompanied by increased brain activity and improved connectivity and function of brain areas responsible for controlling movement.

A recent study has even shown that recreational music making (RMM) can be effective at altering gene expression involved in the stress response. This shows that RMM may be more effective than quiet reading at ameliorating stress in a clinical setting. Although more research into this area needs to be completed, it seems that music making and training are beneficial to physical and psychological health.

5. Music training is a rewarding activity. Most important, making music is something most people enjoy. Your brain is more apt to learn if an activity is inherently rewarding and motivating. Studies have shown that listening to music is a rewarding experience in and of itself, activating brain structures involved in reward processing, including the nucleus accumbens, ventral tegmental area, hypothalamus and insula. Scientists have even begun modulating music reward sensitivity in the brain by using transcranial magnetic stimulation. Sensitizing or desensitizing these brain areas shows causal evidence that these circuits are involved in the enjoyment and motivation of music. Furthermore, a recent study has even shown that exposing rats to melodic music increases dopamine and serotonin in the forebrain, which is linked to reward.

In short, making music is truly a whole-brain workout. Although those who begin music training at a young age seem to display the greatest neuroplastic benefits, research shows it is never too late to learn to play an instrument. More research is needed to more fully understand the effect of music training on the brain throughout life; this is something the National Institutes of Health has recognized.

Meanwhile go learn to play a Bach prelude or *Heart and Soul.* I promise your brain will thank you.

Frank Martela, Ph.D., is a researcher specializing in both the psychology and the philosophy of well-being and meaning in life. He is currently based at Aalto University in Finland. He is author of *A Wonderful Life: Insights on Finding a Meaningful Existence* (Harper Design, 2020).

BEHAVIOR & SOCIETY

Be Yourself—Everyone Else Is Taken

How to find meaning in life through authentic and autonomous living

One of my favorite studies on the meaning in life asked students to write about their "true self," about "who you believe you really are." Another group of students was asked to write about their "everyday self" as defined by how they actually behave in their daily life, and a third group of students was asked to write about the campus bookstore. After the writing task, the students were then asked to rate their meaning in life.

The researchers, led by Rebecca Schlegel of Texas A&M University, were interested in how much detail the participants provided in their various essays, their assumption being that the more detailed a description one provides about one's true self, the more likely one is to be authentically in touch with that sense of self. Not surprisingly, for those people writing about their everyday self

GARY ELLIS *GETTY IMAGES*

or about the campus bookstore, the amount of detail did not have any connection with their sense of meaning in life. When people wrote about their true selves, however, the more detailed the essay, the more the person on average experienced meaning in life.

Here Schlegel's empirical research backs up what existentialist philosophers such as Jean-Paul Sartre and great humanistic psychologists such as Carl Rogers and Abraham Maslow proposed decades ago: There is inherent value in being able to live authentically and express oneself, and such self-actualization can make our lives feel truly worth living. As the late philosopher Lawrence Becker proclaimed, "Autonomous human lives have a dignity that is immeasurable, incommensurable, infinite, beyond price."

This theoretical insight is backed up by recent empirical research in self-determination theory, which has argued forcefully that autonomy is a fundamental human need, the satisfaction of which is important for our psychological growth, integrity and well-being. Just as our body needs food and water for its wellness and health, our mind needs a few basic psychosocial experiences for its wellness and health—and among these needs, autonomy stands tall. Self-determination theory is currently the most studied theory of motivation in psychology, and there are literally hundreds of studies demonstrating the importance of autonomy for human well-being in various life domains ranging from educational outcomes and work engagement to sport performance and dental hygiene.

Autonomy is about being the author of your own life: making volitional choices to live according to your own preferences, to engage in activities that you find personally interesting and that express who you are, and to pursue goals you find worthy.

Given that the need for autonomy is built into the human motivational system, it is no wonder that we find something inherently worthy and fulfilling in being able to live authentically. Basic psychological needs provide a robust foundation for where to find meaning in life, as I argue in my new book, *A Wonderful Life: Insights on Finding a Meaningful Existence*. And what applies to whole lives is true also for individual tasks. Hong Zhang of Nanjing University demonstrated that how much autonomy people perceive in goal pursuit is connected to how meaningful they experienced the goal engagement to be. In my own studies, I have shown how having autonomy at work is one of the key qualities that makes work meaningful.

In order to live a meaningful life, then, make sure you are in touch with yourself—that you are living a life endorsed by yourself, not a life aimed at pleasing others. If you do not follow your own values and dreams, you are most probably following values set by others—in the worst case, the shallow, materialistic values promoted by mass culture and advertisements. And there is nothing more disappointing in life than living someone else's dream. As some wisecracker put it, it is better to be yourself, as everyone else is already taken.

Meaningfulness is about connection. Although this means that a major part of the meaningfulness in our lives comes from connecting with others through intimate, caring relationships and through being able to contribute to society and those one cares about, you cannot connect with others unless you are first in touch with yourself. Otherwise, it is not you who is connecting to others but just an empty shell. Only by knowing who you are and where you come from can you start to authentically connect with others.

Autonomy is about being the author of your own life: making volitional choices to live according to your own preferences, to engage in activities that you find personally interesting and that express who you are, and to pursue goals you find worthy. And therein lies a recipe for more meaningful living.

So take a moment today to write about your true self and who you believe you really are as a person, what your most important values are, and what you yourself would like to pursue and have in life. Then start to figure out how you could make that true self more the self that is realized in your everyday life and work.

Pragya Agarwal is a behavioral and data scientist, a freelance journalist, and author of the book *Sway: Unravelling Unconscious Bias* (Bloomsbury, 2020).

BEHAVIOR & SOCIETY

What Neuroimaging Can Tell Us about Our Unconscious Biases

It reveals that they involve the amygdala, the prefrontal cortex, the posterior cingulate and the anterior temporal cortex

YUICHIRO CHINO GETTY IMAGES

If you have seen the documentary *Free Solo,* you will be familiar with Alex Honnold. He ascends without protective equipment of any kind in treacherous landscapes where above about 15 meters any slip is generally lethal. Even just watching him pressed against the rock with barely any handholds makes me feel nauseated. In a functional magnetic resonance imaging (fMRI) test, neurobiologist Jane Joseph found that there was nearly zero activation in Honnold's amygdala. This is a highly unusual brain reaction and may explain why he feels no threat in free solo climbs that others would not dare attempt. But this also shows how our amygdala activates in that split second to warn us and why it plays an important role in our unconscious biases.

Having spent many years researching unconscious bias for my book, I have realized that it remains problematic to pinpoint because it is hidden and is often in complete contrast to our expected beliefs. Neuroimaging research is beginning to give us more insight into the formation of our unconscious biases. Recent fMRI neuroscience studies demonstrate that people use different areas of the brain when reasoning about familiar and unfamiliar situations.

The neural zones that respond to stereotypes primarily include the amygdala, the prefrontal cortex, the posterior cingulate and the anterior temporal cortex, and they are described as all “lighting up

like a Christmas tree" when stereotypes are activated (certain parts of the brain become more activated than others during certain tasks). People also use different areas of the brain when reasoning about familiar and unfamiliar situations. When we meet someone new, we are not merely focusing on our verbal interaction.

Within a few seconds, we turn behaviors into neural signals with identifiable information about the person to form an impression of them while our prefrontal cortex simultaneously monitors neural information from our five senses, focusing us on social norms or personal preferences. So while we are evaluating someone, we are also assigning that person certain labels and stereotypes. But we are not aware of this because the prefrontal cortex can engage in this outside our conscious awareness. These decisions are taken on a subconscious level before we go into the more conscious, slow and controlled processing.

The amygdala is likely to activate as we walk down an unfamiliar, dark alleyway and hear unexpected sounds or see a stranger walking toward us. It causes us to make assumptions about the threat level of the situation. We are likely to feel a flood of emotions as our heart starts beating faster and our palms become sweaty. Evolutionarily, humans are primed to respond to any notion of threat to ensure fitness and survival, so this kind of response is crucial. This all happens without any conscious reasoning or effort. It then takes explicit engagement on our part to involve the prefrontal cortex, which gives the message to our amygdala that all is under control and there is nothing to worry about, that perhaps that stranger is a neighbor and that the sound we heard is possibly only an owl.

Neuroplasticity is one of the major breakthroughs in neurosciences: we now know that different short- and long-term experiences will change the brain's structure.

Our conscious brain does not have the opportunity to interpret all the information we see, so our initial instincts are less likely to be based on fully processed interpretations and often include biases of some kind. As time passes, our socialization and our personal memories and experiences produce unconscious biases, and these biases are applied while the amygdala labels and categorizes incoming stimuli efficiently and unconsciously, leading us to rapidly categorize others as "like me" or "not like me" and, consequently, as "in-group" or "out-group." This is the root of prejudice and discrimination.

Research using fMRI has given us an insight into how we respond to biases at a neural level and how intergroup prejudices activate areas of our brain associated with threat and fear. It has also given us more insight into the way we form in-group favoritism and associations and into how negative outgroup biases are even more prominent than in-group empathy. We respond more strongly to negative news and information than to positive stimuli. Results from fMRI studies show that when individuals see facial images of people with an ethnic background different from their own, it often activates the amygdala more than seeing people of the same ethnicity. The way we respond to different accents can also be explained by amygdala response to in-group and out-group memberships. Whereas repetition of our own accent elicits an enhanced neural response, repetition of another group's accent results in reduced neural responses.

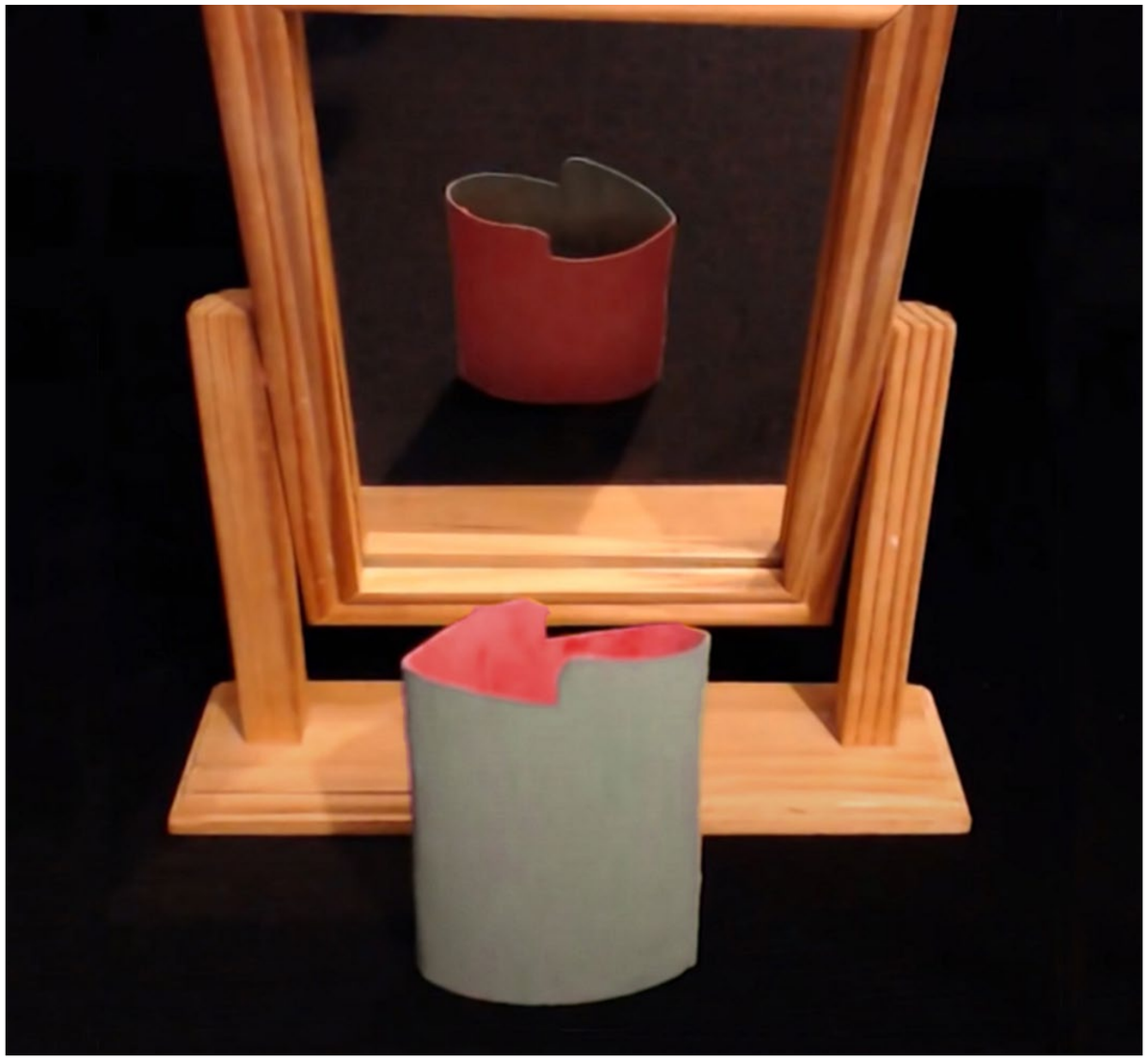
Neuroplasticity is one of the major breakthroughs in neurosciences: we now know that different short- and long-term experiences will change the brain's structure. Social attitudes and expectations such as stereotypes can change how the brain processes information, and so brain-based differences in behavioral characteristics and cognitive skills change across time, place and culture. This means that our unconscious biases are not wired into us. They are learned through our experiences and hence can also be unlearned.

The results from these studies are not foolproof, and the limitations of fMRI should be understood and acknowledged. To understand the underlying neural landscape of cognitive biases better, we need to ensure that the absence of activity in a brain region does not necessarily imply that it is not involved in the creation or reinforcement of a specific bias. I believe, however, that it would be of immense benefit if we can translate knowledge about the neurobiology of our underlying behavior into designing interventions for addressing bias, especially that which creates stigma and discrimination.

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*.

Wrong-Headed Arrows

This illusion takes the right of way with your perspective



MATTHEW PRITCHARD

Now that you are fully stocked up on toilet paper, you must be wondering what to do with the cardboard tubes inside the rolls. This is your opportunity to put your hoarded supplies to good use by blowing the minds of your socially distanced friends and family. So grab some leftover toilet paper tubes, a pair of scissors and a mirror for an experiment that will change your perspective.

In the photograph, an arrow and its reflection point away from each other. Impossible, you say? The explanation goes back to the moment in which Kokichi Sugihara, a mathematical engineer at Meiji University in Japan, discovered what he thought was a bug in his software. After writing a computer program to produce 3-D models from architectural blueprints, Sugihara tested his software by feeding it impossible images: illusions such as the Penrose steps in M. C. Escher's *Ascending and Descending* lithograph, which appear to go infinitely up *and* down. Sugihara reasonably assumed that his code would spit out an error when confronted with the impossible. Instead the program interpreted the illusions as *possible* objects that only looked impossible from a specific vantage point. That is when the mathematician became an illusionist.

Sugihara later incorporated mirrors into his illusory creations—for example, to make an object's reflection seem incompatible with the original, such as with two arrows pointing in opposite directions. Matthew Pritchard, a British physicist and magician, recently developed the toilet-paper-roll variant of Sugihara's arrow illusion that we feature here. To build your own version, all you need to do is cut the top of a cardboard tube in a simple pattern that makes it look like an arrow pointing to the same side no matter which way you turn it because of your perspective of the near edge versus the far edge of the tube.

To take your handiwork to the next level, prepare a dozen or so cardboard tubes cut in the same way and arrange them around the edge of your Lazy Susan or glass-plate microwave turntable. As the plate rotates, the impossible arrows never do! You can find the construction steps in Pritchard's finalist video from the 2019 Best Illusion of the Year Contest.

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