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PLUS

DEBATE OVER THE POWER OF "GROWTH MINDSETS"

NEW TOOLS TO MEASURE CONSCIOUSNESS

HOW TO GET PAST SHAME

Embracing Our Fear

It's a hardwired response, but it doesn't have to rule our emotions

WITH COVERAGE FROM nature

LIZ TORMES

SCIENTIFIC AMERICAN MIND

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The Fearful Mind

Nearly one fifth of the U.S. adult population suffers from an anxiety disorder, according to 2018 data. At their core, the worry and panic that make up general anxiety stem from an overactive fear response in the brain. And indeed, that primordial reaction is one of the most examined topics in neuroscience—investigated in rodents, humans, other apes and even invertebrates. But how much do those automatic feelings relate to the emotions that humans associate with fear and, subsequently, their experience in the world? To sort out the issue, as six neuroscientists discuss in a fascinating Q&A in these pages, step one is for the field to come to agreement over an exact definition of fear and how best to study it (see "Embracing Our Fear").

If you worry about whether your life is "happy enough," focus instead on the meaningful experiences in your life, both good and bad, writes Scott Barry Kaufman (see "Forget Happiness, Find Meaning"). And in one of my favorite features of the year, check out the winners in the annual Art of Neuroscience photography competition (see "The Brain in Images: Top Entries in the Art of Neuroscience"). They are a beautiful new way to think of your mind.

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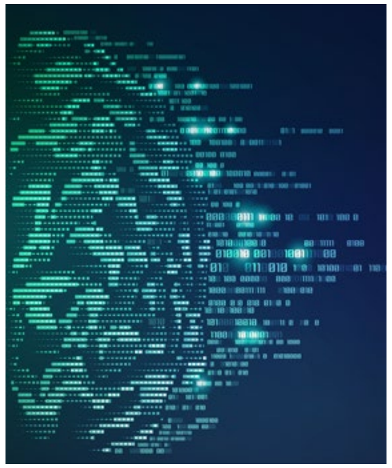

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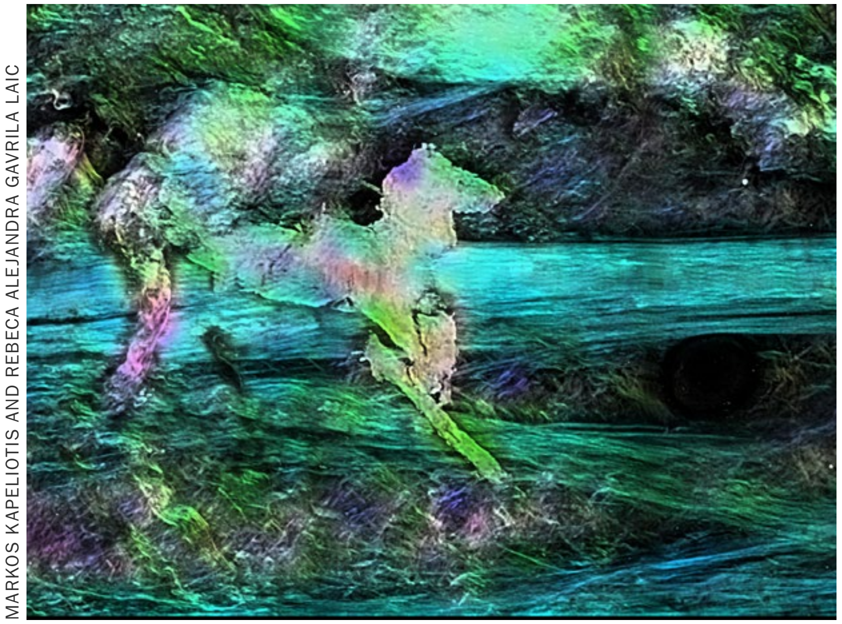

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NEWS

Debate Arises over Teaching "Growth Mindsets" to Motivate Students

Research shows conflicting data on the impact of the intervention, but a major new study confirms it can work

IN HER 2006 book *Mindset*, psychologist Carol Dweck of Stanford University identified the power of beliefs. "They strongly affect what we want and whether we succeed in getting it," she wrote. "Changing people's beliefs—even the simplest beliefs—can have profound effects." She then argued that people who possess "fixed mindsets" believe their intelligence or personality cannot change. They are more likely to focus on performing well on familiar tasks, to shy away from challenge and to be

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less resilient in the face of failure. By contrast, those with a "growth mindset" believe their intelligence or personality is malleable. They see challenge as an avenue to improvement and are better prepared to learn. Dweck cited exemplars of growth mindsets, including Michael Jordan, Charles Darwin, photographer Cindy Sherman and Lou Gerstner, who rescued IBM.

The idea quickly caught the public imagination, and the book became a best seller. Dweck's TED talk has nearly 10 million views. The mindset approach has been applied in stress and mental health research, in conflict resolution and in corporate boardrooms. But it has been especially influential in education as a way to help students, low achievers in particular, reach their full potential. After the success of Dweck's book, schools around the world began to teach mindsets as a learning technique, and companies sprang up selling mindset materials to teachers and parents.

Then came the pushback. Like several other major ideas from psychology, mindset research, which began in the 1980s, has been reexamined in the current rigorous era of social science. A soon-to-be published study that attempted to replicate two of Dweck's most-cited papers reported "little or no support for the idea that growth mindsets are beneficial for children's responses to failure or school attainment." And while some mindset-based education interventions had good results, others found no effect on student outcomes.

A few methodological questions about Dweck's work have emerged (as have questions about the replications and failed interventions), but the loudest criticism makes the claim that mindset research overpromised and underdelivered. "Millions of dollars have gone into funding mindset research. If it turns out this doesn't work, that's a massive lost opportunity," says psychologist Timothy Bates of the University of Edinburgh, senior author of the replication study.

Even mindset's proponents recognize that the concept was disseminated too far too fast. "Any popular idea in education gets spread way ahead of how ready the science is," says psychologist David Yeager of the University of Texas at Austin. He is a leader among the new generation of mindset researchers that has begun to refine the science underlying interventions. Dweck says she used to think that growth mindset was a simple concept. "But then we started becoming aware of all the ways that it might be misunderstood or not implemented in a compelling way. One thing we've learned in the past five to 10 years is how the nuances matter."

"Millions of dollars have gone into funding mindset research. If it turns out this doesn't work, that's a massive lost opportunity."

—Timothy Bates

Yeager and Dweck's latest work takes these subtleties into account. A paper they and their colleagues published on August 7 in *Nature* confirms that mindset interventions can work at scale, especially for low-achieving students, but that context is critical. Exposure to two short, low-cost online programs led to higher grades for lower-achieving ninth graders (the average improvement was 0.1 grade point). Schools that fostered climates celebrating academic success and curiosity saw the largest gains: some students got another half a grade point or slightly more, and the likelihood of failure (a D or F average) fell by 8 percent. In addition, high- and low-achieving ninth graders chose more challenging math courses in 10th grade.

The study is notable not only for its findings but for its methods, which met today's exacting scientific requirements and then some: It is a randomized controlled trial of more than 12,000 students from a nationally representative sample of public schools. The authors preregistered their hypotheses and analysis plan (a step that prevents fishing for positive results), and the intervention was administered by an independent research firm. The statistical analysis was reviewed independently, too. The work has also been replicated by a separate set of researchers in a study of more than 6,500 students in Norway. (That replication will be published separately.)

Some question whether this level of

improvement—a mere 0.1 grade point boost, for instance—is meaningful. "They're claiming what most people think of as minuscule effects," Bates says. "This best case cannot be even a tiny part of a solution to the problems that need solving in education." That critique mirrors other reviews of mindset research. In two meta-analyses, cognitive psychologist Brooke Macnamara of Case Western Reserve University and her colleagues found what they considered "weak" effects that were similar to the findings in the new national study. If the results are not going to be "profound," Macnamara says, "the companies that sell growth-mindset-intervention products should be clear about that in their advertising."

But educational economists such as Susan Dynarski of the University of Michigan have argued that educational interventions must be judged in real-world settings, where small effects can be important. Matthew Kraft, an educational economist at Brown University, has reviewed almost 800 randomized controlled trials of education interventions and found a median effect size of 0.1 standard deviation on student achievement outcomes. By comparison, the mindset study's intervention was more effective than half of those interventions, which is particularly impressive for such a short, inexpensive program, says Kraft, who was not involved in the work but is part of the Mindset Scholars Network. That small bump in grade point average, he argues, could be the difference between a student passing or failing exit exams or being eligible for an Advanced Placement course.

IN PRAISE OF EFFORT

The concept of mindsets was a direct response to the self-esteem movement. A seminal series of Dweck's studies, published in 1998, concerned the effect of praise on motivation. Dweck, then at Columbia University, and one of her colleagues administered a series of puzzles to about 400 fifth graders. After completing the first puzzle, children praised for their effort ("You must have worked hard") as opposed to their intelligence ("You must be smart") were far more likely to choose a more challenging puzzle to do next. In 2007, after moving to Stanford, Dweck and psychologist Lisa Blackwell, then at Columbia, conducted another important study. They followed 373 seventh graders to see whether mindset predicted grades two years later. With a subset of students, they also performed the first mindset intervention, explicitly teaching kids about the brain and that intelligence can be developed. Having a growth mindset predicted higher grades, while a fixed mindset predicted a flat-grade trajectory. Compared with those who did not receive the intervention, those who did showed greater motivation in the classroom.

Like many mindset researchers, Yeager encountered Dweck's work as a graduate student at Stanford. He had taught middle school and wanted to use mindsets to improve education. During graduate school, he worked at the nearby Carnegie Foundation for the Advancement of Teaching, where he became interested in the challenge of effectively implementing academic theories at scale. He was encouraged by a Carnegie project called Statway, which, in part, used growth mindset instruction to help community college students pass remedial math courses (a barrier for many in getting their degree).

In 2015 Dweck, Yeager and others co-founded the Mindset Scholars Network, an interdisciplinary group dedicated to furthering research on learning mindsets. Yeager also began organizing the ambitious national study he and Dweck have just published. That meant developing an effective, brief intervention that could be delivered directly to students. Larger, longer interventions with trained instructors had been found to work well and might have produced stronger results, but they would not be feasible in thousands of schools with many competing demands for classroom time. The final materials, which will be free to educators and researchers, consist of two 25-minute online sessions. They describe the brain as a muscle that grows stronger with use and include a letter-writing activity to help kids internalize the message.

At the same time, Dweck realized that there were problems with how mindsets were being used. Pinning a poster about growth mindset on the wall of a classroom does not help if the teacher creates an environment where kids are afraid of making a mistake, she says. "The environment has to support the belief change and the behaviors that come with it." She began to warn of "false growth mindset" and included a new chapter to address the subject in an updated edition of *Mindset*. "The important thing is learning in progress," she says. "That is brought about not only by effort but by trying new strategies and by seeking appropriate help and input." Dweck also divested her interest in Mindset Works, a company that sells mindset materials under the brand Brainology. (Her former colleague Blackwell remains involved with Brainology, and there is still a link to the company on the Web site for Dweck's book.)

The attempted replication of Dweck's work that is about to be published concerned the 1998 study on praise and part of the 2007 study. Bates and his student Yue Li conducted a series of studies in a group of more than 600 Chinese students. Their results were mixed but mostly found no effect. The positive effects they found were of much smaller magnitude than in Dweck's studies. "It just wasn't working strongly enough or reliably enough to be anything other than an artifact," Bates says. Yeager and Dweck question some of Bates's findings, and Dweck reanalyzed her data and made them publicly available. The debate is likely to continue in the coming months in academic journals. For now, Dweck is proud of her work on praise and stands by it, and she notes that praise is not part of the mindset intervention in the national study.

Attempted interventions in the U.K., Peru and Argentina are more comparable. In Peru, there were positive effects in one out of three school districts. In the U.K. and Argentina, there were none. Alejandro Ganimian, an assistant professor of psychology and economics at New York University, who led the Argentina study, says, "It seemed to me at the start that it would be more simplistic. It's humbling." He isn't giving up yet and plans to do some smaller pilot tests and to investigate possible reasons the program did not work, including the intervention design or the age of the students (he studied 12th graders).

Dweck and Yeager's recent *Nature* findings underscore the realization that successful mindset interventions appear to require finesse. "The national study showed us how much more there is to learn," Yeager says. They spent years fine-tuning the materials they used and are confident in their appropriateness for ninth graders but cannot be sure about other populations or about the materials used in other interventions. "Just because it's easy to deliver doesn't mean it's easy to develop," Yeager says.

"We have really good evidence that under the right conditions, you can lift a portion of that burden of the fixed mindset from students."

—David Yeager

Education is not the only field where mindset interventions are being tested. Clinical psychologist Jessica Schleider of Stony Brook University studies the effectiveness of brief interventions in treating adolescent depression and anxiety. In mindsets, she saw parallels with cognitive-behavioral therapy, which teaches individuals they have agency over their thoughts and behaviors. With John Weisz of Harvard University, Schleider created a short intervention that generated significant improvements in both parent- and youth-reported levels of depression. Mindful of the backlash against mindsets in education, Schleider intends to proceed slowly. "I want to really understand what we're doing, why exactly it's working and what the component parts are before heading to dissemination," she says.

The new motto for mindset science, then, seems to be this: tone down the hype and hone the details. Dweck and Yeager hope to build on their national study to learn more about what makes for a fertile learning environment and how to create supportive conditions elsewhere. "We have really good evidence that under the right conditions, you can lift a portion of that burden of the fixed mindset from students," Yeager says. "That is a valid thing to be working on as a school. The treatment gives students a hypothesis about their own learning and what high school is like. It is up to us to create an environment in which that hypothesis is true."

—Lydia Denworth

Editor's Note: This story was edited after posting. It originally described Jessica Schleider as a cognitive psychologist.

The Technology of Kindness

How social media can rebuild our empathy—and why it must

IN THE RUN-UP to the 1964 World's Fair, the great science-fiction writer Isaac Asimov was asked what that same event might look like 50 years later. He guessed that by 2014, we'd be in the constant company of "electroluminescent panels"—used for video chat, navigation and, more deeply, "to withdraw from nature in order to create an environment that will suit [us] better."

Asimov's future is our present. This worries many people, who think technology has left us dumber, sadder and meaner than we were before. Empathy—people's ability to share and understand one another's emotions—has declined sharply in the 21st century. If it dies out, technology will probably be charged with the murder. The clues are all there: People in countries with a greater Internet penetrance report lower empathy. Simply leaving a phone between two strangers as they talk lessens their resulting trust. The prosecution's case writes itself: while apparently serving us, technology has quietly poisoned the connections that keep us human.

Yet technology and the Internet in particular are not inherently antisocial. They can sap our empathy, but used differently, they could become a world-sized magnifying glass for our better angels. Many corners of the Internet already allow people to broaden their empathy and share collective goodwill. Researchers are pinpointing the ingredients of positive technology. If they become the norm, the future of life online will be kinder than its past. Internet platforms must heed this evidence, and their users must demand them to do so.

People's ability to connect is the glue that holds our culture together. By thinning out our interactions and splintering our media landscape, the Internet has taken away the common ground we need to understand one another. Each of us is becoming more confident about our own world just as it drifts farther from the worlds of others. Empathy requires us to understand that even people who disagree with us have a lived experience as deep as our own. But

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in the fractured landscape of social media, we have little choice but to see the other side as obtuse or dishonest, or both. Unless we reverse this trend and revive empathy, we have little chance of mending the tears in our social fabric.

Technology's socially depleting effects are not coincidental; they reflect how platforms such as Facebook and Twitter are designed—and such platforms are, in turn, shaped by financial incentives. These sites satisfy shareholders not by making users healthy or happy but by keeping them online. This imperative favors extremism, vanity, fear—whatever grabs us and holds on. About 70 percent of YouTube views now come from the site's recommendations, which are optimized to generate clicks. The result is a massive flow of eyeballs to conspiracy theories, bigotry and aggression. This is what former Google ethicist Tristan Harris calls "extractive" technology: it takes advantage of our frailties and gets more effective at harming us as it grows more sophisticated.

Life online changes how we see others and how we are seen. Sometimes we're not seen at all—our face and name are replaced by an avatar and an anonymous character string. Anonymity can be vital—for instance, by allowing people to safely organize protests in totalitarian nations. But it also cuts the brake lines on social interactions, encouraging people to try cruelty on like a mask, knowing it won't cost them. Cyberbullying follows people into their homes and beds and leaves its victims more suicidal than those of traditional bullying.

When we are seen online, the Internet's token economy can pervert how we present ourselves. In a 2017 study, psychologist William Brady and his colleagues analyzed more than 500,000 tweets to examine what makes them go viral. They found that the more "moral emotion"—such as outrage—a post contained, the more it was retweeted, especially within the original poster's ideological circles. Retweets are tiny, addictive affirmations, which reinforce outrage. After being rewarded with attention, people responded by making their later tweets even more aggrieved than before. Twitter not only reflects an angry world; it helps create one.

Social media makes us less social when it replaces rich, analog hangouts with strings of text and curated images. In a 2017 set of studies, Juliana Schroeder of the University of California, Berkeley, and her colleagues taped individuals as they described their opinion on polarizing political issues. A separate set of "evaluators" either listened to those recordings or read their transcripts. Evaluators were more likely to dehumanize speakers when their opinions were reduced to text, especially when the evaluators disagreed with them. Thinned-out interactions made empathy harder to access.

Diagnosing technology's damaging effects is the first step toward reversing them. Harris co-founded the Center for Humane Technology to encourage developers and investors to build "regenerative," rather than extractive, online platforms. The idea is that our capacity for empathy runs just as deep as our vanity, outrage or fear, and technology should highlight healthier forces.

Some sites are purposefully built to favor connection and understanding. On ChangeAView, people post their opinion on a range of topics, inviting fellow posters to persuade them otherwise. Commenters are rewarded not for trolling or shaming but for "deltas"—an indication their argument changed someone's mind. The result is a feast of thoughtful, genuine dialogue among people who might not otherwise engage with one another.

Technology also builds new communities around kindness. Consider the paradox of rare illnesses such as cystic fibrosis or myasthenia gravis. Each affects fewer than one in 1,000 people, but there are many such conditions, meaning there are many people who suffer in ways their friends and neighbors don't understand. Millions have turned to online forums, such as Facebook groups or the site RareConnect. In 2011 Priya Nambisan, a health policy expert, surveyed about 800 members of online health forums. Users reported that these groups offer helpful tips and information but also described them as heartfelt communities, full of compassion and commiseration.

Other platforms, such as Koko and 7 Cups, have scaled this approach, allowing anyone to count on the kindness of strangers. These sites train users to provide empathetic social support and then unleash their goodwill on one another. Some express their struggles; others step in to provide support. Users find these platforms deeply soothing. In a 2015 survey, 7 Cups users described the kindness they received on the site to be as helpful as professional psychotherapy. Users on these sites also benefit from helping others. In a 2017 study, psychologist Bruce Doré and his colleagues assigned people to use either Koko or another Web site and tested their subsequent well-being. Koko users' levels of depression dropped after spending time on the site, especially when they used it to support others.

Sites such as ChangeAView and

7 Cups can appear like oases of connection in a landscape bereft of it—exceptions that prove the rule. But what sets connected platforms apart is their break from common, antisocial online practices. They allow people to be vulnerable and visible to one another and reward them for listening rather than shouting. Other social media companies could follow suit: by reforming their incentive structures such that open-minded, positive posts rise more quickly or by facilitating longer, richer communication between users. But they must make progress on this mission intentionally and soon.

Mark Zuckerberg famously exhorted his employees to "move fast and break things." By now it's clear they've broken quite a lot. No matter how much we decry the effects of technology, there's no going back. But we can get better at detecting what life online does to us and how it could do better. This could begin with the companies that build social media platforms, but users could be forgiven for not trusting tech giants to have our best interests in mind. Restorative online technology will grow only when we demand it from them.

—Jamil Zaki

New Clues Found in Understanding Near-Death Experiences

Research finds parallels to certain psychoactive drugs

CANDACE MICKLER *GETTY IMAGES*

IMAGINE A DREAM in which you sense an intense feeling of presence, the truest, most real experience in your life, as you float away from your body and look at your own face. You have a twinge of fear as memories of your life flash by, but then you pass a transcendent threshold and are overcome by a feeling of bliss. Although contemplating death elicits fear for many people, these positive features are reported in some of the near-death experiences (NDEs) undergone by those who reached the brink of death only to recover.

Accounts of NDEs are remarkably consistent in character and content. They include intensely vivid memories involving bodily sensations that give a strong impression of being real, more real even than memories of true events. The content of those experiences famously includes memories of one's life "flashing before the eyes," as well as the sensation of leaving the body, often seeing one's own face and body, blissfully traveling through a tunnel toward a light and feeling "at one" with something universal.

Not surprisingly, many have seized on NDEs as evidence of life after death, heaven and the existence of

God. The descriptions of leaving the body and blissful unity with the universal seem almost scripted from religious beliefs about souls leaving the body at death and ascending toward heavenly bliss. But these experiences are shared across a broad range of cultures and religions, so it's not likely that they are all reflections of specific religious expectations. Instead that commonality suggests that NDEs might arise from something more fundamental than religious or cultural expectations. Perhaps NDEs reflect changes in how the brain functions as we approach death.

Many cultures employ drugs as part of religious practice to induce feelings of transcendence that have similarities to near-death experiences. If NDEs are based in brain biology, perhaps the action of those drugs that causes NDE-like experiences can teach us something about the NDE state. Of course, studying NDEs has significant technical hurdles. There is no way of examining the experience in animals, and rescuing a patient at death's door is far more important than interviewing them about their NDE. Moreover, many of the drugs used to induce religious states are illicit, which would complicate any efforts to study their effects.

Although it's impossible to directly examine what happens to the brain during NDEs, the stories collected from them provide a rich resource for linguistic analysis. In a fascinating new study, NDE stories were compared linguistically with anecdotes of drug experiences to identify a drug that causes an experience most like a near-death experience.

What is remarkable is how precise a tool this turned out to be. Even though the stories were open-ended subjective accounts often given many years after the fact, the linguistic analysis focused down not only to a specific class of drugs but also to a specific drug as causing experiences very similar to NDEs.

This new study compared the stories of 625 individuals who reported NDEs with the stories of more than 15,000 individuals who had taken one of 165 different psychoactive drugs. When those stories were linguistically analyzed, similarities were found between recollections of near-death and drug experiences for those who had taken a specific class of drug. One drug in particular, ketamine, led to experiences very similar to NDE. This may mean that the near-death experience may reflect changes in the same chemical system in the brain that is targeted by drugs like ketamine.

The researchers drew on a large collection of NDE stories they had collected over many years. To compare NDEs with drug experiences, the researchers took advantage of a large collection of drug experience anecdotes found in the Erowid Experience Vaults, an open-source collection of accounts describing firsthand experiences with drugs and various substances.

In this study, the recollections of those who experienced NDEs and those who took drugs were compared linguistically. Their stories were broken down into individual words, and the words were sorted according to their meaning and counted. In this way, researchers were able to compare the number of times words having the same meaning were used in each story. They used this numerical analysis of story content to compare the content of drug-related and near-death experiences.

Each of the drugs included in these comparisons could be categorized by their ability to interact with a specific neurochemical system in the brain, and each drug fell into a specific category (antipsychotic, stimulant, psychedelic, depressant or sedative, deliriant or hallucinogen). Few similarities were found when the accounts of one stimulant drug were compared with another within the same stimulant drug class, and few if any similarities were found between accounts of stimulant drug experience and NDEs. The same was true for depressants.

The stories associated with hallucinogens, however, were very similar to one another, as were stories linked to antipsychotics and deliriants. When recollections of drug effects were compared with NDEs, stories about hallucinogens and psychedelics had the greatest similarities to NDEs, and the drug that scored the highest similarity to NDEs was the hallucinogen ketamine.

The word most strongly represented in descriptions of both NDEs and ketamine experiences was "reality," highlighting the sense of presence that accompanies NDEs. High among the list of words common to both experiences were those related to perception (saw, color, voice, vision), the body (face, arm, foot), emotion (fear) and transcendence (universe, understand, consciousness).

The researchers then sorted words into five large principal groups according to their common meaning. Those principal components dealt with perception and consciousness, drug dependency, negative sensations, drug preparation, as well as a group that included disease state, religion and ceremony. NDEs reflected three of these components related to perception and consciousness, religion and ceremony, disease state, and drug preparation.

The component related to perception and consciousness was labeled "Look/Self" and included terms such as color, vision, pattern, reality and face. The component "Disease/Religion" contained elements such as anxiety, ceremony, consciousness and self, whereas the component related to preparation "Make/Stuff" contained elements such as prepare, boil, smell and ceremony. Again, ketamine had the greatest overlap with NDEs in this type of analysis.

Other drugs that cause similar experiences to NDEs include LSD and *N,N*-Dimethyltryptamine (DMT). The famous hallucinogen LSD was as similar as ketamine to NDEs when the near-death event was caused by cardiac arrest. DMT is a hallucinogen found in South American plants and used in shamanistic rituals. It caused experiences like NDEs and is also made in the brain, leading to speculation that endogenous DMT may explain NDEs. It is not known, however, whether levels of DMT change in a meaningful way in the human brain near death, so its role in the phenomenon remains controversial.

This study has significant weaknesses because it is based on purely subjective reports—some taken decades after the event. Similarly, there is no way to substantiate the accounts in the Erowid collection as there is no way to prove that any individual took the drug they claimed or believed they were taking. This makes it all the more remarkable that a linguistic analysis of stories derived in this manner could discriminate among different drug classes in their similarities to NDEs.

Linking near-death experiences and the experience of taking ketamine is provocative, yet it is far from conclusive that both are because of the same chemical events in the brain. The types of studies needed to demonstrate this hypothesis, such as measuring neurochemical changes in the critically ill, would be both technically and ethically challenging.

The authors propose, however, a practical application of this relation. Because near-death experiences can be transformational and have profound and lasting effects on those who experience them, including a sense of fearlessness about death, they suggest that ketamine could be used therapeutically to induce an NDE-like state in terminally ill patients as a "preview" of what they might experience, so as to relieve their anxieties about death. Those benefits need to be weighed against the risks of potential ketamine side effects, which include feelings of panic or extreme anxiety, effects that could defeat the purpose of the intervention.

More important, this study helps describe the psychological manifestations of dying. That knowledge may ultimately contribute more to alleviating fear of this inevitable transition than a dose of any drug.

—Robert Martone

A Successful Artificial Memory Has Been Created

The growing science of memory manipulation raises social and ethical questions

WE LEARN FROM our personal interaction with the world, and our memories of those experiences help guide our behaviors. Experience and memory are inexorably linked, or at least they seemed to be before a recent report on the formation of completely artificial memories. Using laboratory animals, investigators reverse engineered a specific natural memory by mapping the brain circuits underlying its formation. They then "trained" another animal by stimulating brain cells in the pattern of the natural memory. Doing so created an artificial memory that was retained and recalled in a manner indistinguishable from a natural one.

Memories are essential to the sense of identity that emerges from the narrative of personal experience. This study is remarkable because it demonstrates that by manipulating

specific circuits in the brain, memories can be separated from that narrative and formed in the complete absence of real experience. The work shows that brain circuits that normally respond to specific experiences can be artificially stimulated and linked together in an artificial memory. That memory can be elicited by the appropriate sensory cues in the real environment. The research provides some fundamental understanding of how memories are formed in the brain and is part of a burgeoning science of memory manipulation that includes the transfer, prosthetic enhancement and erasure of memory. These efforts could have a tremendous impact on a wide range of individuals, from those struggling with memory impairments to those enduring traumatic memories, and they also have broad social and ethical implications.

In the recent study, the natural memory was formed by training mice to associate a specific odor (cherry blossoms) with a foot shock, which they learned to avoid by passing down a rectangular test chamber to another end that was infused with a different odor (caraway). The caraway scent came from a chemical called carvone, whereas the cherry blossom scent came from another chemical, acetophenone. The researchers found that acetophenone activates a specific type of receptor on a discrete type of olfactory sensory nerve cell.

They then turned to a sophisticated technique, optogenetics, to activate those olfactory nerve cells. With optogenetics, light-sensitive proteins are used to stimulate specific neurons in response to light delivered to the brain through surgically implanted optic fibers. In their first experiments, the researchers used transgenic animals that only made the protein in acetophenone-sensitive olfactory nerves. By pairing the electrical foot shock with optogenetic light stimulation of the acetophenone-sensitive olfactory nerves, the researchers taught the animals to associate the shock with activity of these specific acetophenone-sensitive sensory nerves. When they later tested the mice, they avoided the cherry blossom odor.

These first steps showed that the animals did not need to actually experience the odor to remember a connection between that smell and a noxious foot shock. But this was not a completely artificial memory, because the shock was still quite real. To construct an entirely artificial memory, the scientists needed to stimulate the brain in such a way as to mimic the nerve activity caused by the foot shock as well.

Earlier studies had shown that specific nerve pathways leading to a structure known as the ventral tegmental area (VTA) were important for the aversive nature of the foot shock. To create a truly artificial memory, the researchers needed to stimulate the VTA in the same way as they stimulated the olfactory sensory nerves, but the transgenic animals only made the light-sensitive proteins in those nerves. To use optogenetic stimulation, they stimulated the olfactory nerves in the

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same genetically engineered mice, and they employed a virus to place light-sensitive proteins in the VTA as well. They stimulated the olfactory receptors with light to simulate the odor of cherry blossoms, then stimulated the VTA to mimic the aversive foot shock. The animals recalled the artificial memory, responding to an odor they had never encountered by avoiding a shock they had never received.

For a long time, it has been a mystery how memories are formed in the brain—and what physical changes in the brain accompany their formation. In this study, the electrical stimulation of specific brain regions that led to a new memory also activated other brain regions known to be involved in memory formation, including an area called the basolateral amygdala. Because nerve cells communicate with one another through junctions called synapses, it has been assumed that changes in synaptic activity account for the formation of memories.

In simple animals, such as the sea slug *Aplysia*, memories can be transferred from one individual to another using RNA extracted from the one who experienced them. The RNA contains the codes for proteins made in the nerves of the animal associated with the memory.

Memories have been partially transferred in rodents by using recordings of electrical activity of a trained animal's memory center (the hippocampus) to stimulate similar patterns of nerve activity in a recipient animal. This process is similar to the new report described here, in that stimulating the electrical activity of specific neural circuits is used to elicit a memory. In the case of memory transfer, that pattern came from trained animals, whereas in the optogenetics study, the pattern of electrical activity associated with the memory was built de novo within the brain of the mouse. This is the first report of a completely artificial memory, and it helps to establish some fundamental understanding of how memories may be manipulated.

Research into memory and efforts to manipulate it have progressed at a rapid pace. A "memory prosthetic" designed to enhance its formation and recall by electrical stimulation of the memory center in the human brain has been developed with support from the Defense Advanced Research Projects Agency (DARPA). In contrast, memory erasure using what has been nicknamed the Eternal Sunshine drug (zeta inhibitory peptide, or ZIP)—after *Eternal Sunshine of the Spotless Mind*, a Hollywood movie with a mnemonic theme—is being developed to treat recollections of chronic pain.

For a long time, it has been a mystery how memories are formed in the brain—and what physical changes in the brain accompany their formation.

There are legitimate motives underlying these efforts. Memory has been called "the scribe of the soul," and it is the source of one's personal history. Some people may seek to recover lost or partially lost memories. Others, such as those afflicted with post-traumatic stress disorder or chronic pain, might seek relief from traumatic memories by trying to erase them.

The methods used here to create artificial memories will not be employed in humans anytime soon: none of us are transgenic like the animals used in the experiment, nor are we likely to accept multiple implanted fiber-optic cables and viral injections. Nevertheless, as technologies and strategies evolve, the possibility of manipulating human memories becomes all the more real. And the involvement of military agencies such as DARPA invariably renders the motivations behind these efforts suspect. Are there things we all need to be afraid of or that we must or must not do? The dystopian possibilities are obvious.

Creating artificial memories brings us closer to learning how memories form and could ultimately help us understand and treat dreadful diseases such as Alzheimer's. Memories, however, cut to the core of our humanity, and we need to be vigilant that any manipulations are approached ethically.

—Robert Martone

New Insights into Self-Insight: More May Not Be Better

An innovative study technique yields surprising results that counter the popular idea that knowing yourself is good for you

HOW USEFUL IS IT, really, to know thyself? The idea that self-insight is good for us dates all the way back to the inscriptions on ancient Greece's Temple of Apollo in Delphi. It is still popularly assumed that people with a clear view of themselves and their abilities are better off—that they feel better, have more satisfying relationships and are more successful. But when psychologists have tested that premise, they haven't found much strong empirical evidence of the benefits of self-insight for well-being.

An intriguing study recently added provocative findings to this long-standing debate. It tested five of the most common hypotheses on the connection between self-insight and psychological adjustment. Does self-knowledge really lead to higher satisfaction? Is it maybe more productive to just think positively—even if a little overconfidently—about one's abilities? Or could it be that those with the highest abilities will be optimally adjusted? The study, published in July in *Nature Human Behaviour,* found support for none of these ideas.

Instead it tentatively indicated that it is people with the biggest gap between their abilities and their view of themselves who say they have the highest levels of satisfaction with their life, career and relationships. "People who report being more adjusted are those who have a combination of relatively lower true abilities and actual higher views of themselves," says Stéphane Côté, a social psychologist at the Rotman School of Management at the University of Toronto and an author of the paper.

The phrase "know thyself" dates back to the ancients but reappears throughout the historical record and into the modern era. Here is shown a mosaic with the Greek inscription of the saying from the convent of San Gregorio on the Appian Way in Rome.

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Beyond its unanticipated findings, the new study is notable for how it was conducted. It was a registered report, a still relatively rare process that fundamentally shifts the way scientific research is published by front-loading peer review into the planning stages of a study and accepting that study, in principle, for publication before any data have been collected, regardless of the result. Such an approach is expressly intended for confirmatory research comparing competing hypotheses.

By that criterion, the self-insight study was an excellent candidate. It was one of the first two registered reports in *Nature Human Behaviour*. Both appeared in the same issue, along with an editorial on the importance of this new way of doing science. Traditionally, it is mostly "significant" results, meaning those that confirm a hypothesis at a level above statistical significance, that get published. That phenomenon has led to a concern that too much scientific research is left in file drawers and never submitted to a journal, biasing the perception of what is known. "We strongly believe that when the question is important and the methods robust, the results will be important no matter what they are," the authors of the editorial wrote.

"This is a very important piece of work," says psychologist Mitja Back of the University of Münster in Germany, adding that it showcases the advantages of registered reports. (Back served as a reviewer for that study and helped to strengthen the statistical analysis but was otherwise not involved.) "The paper," he says "provides one of the very few direct tests of the assumption that individual differences in self-insight are related to adjustment outcomes."

Others who investigate similar questions found the results intriguing. "This is fascinating work," says social psychologist Cameron Anderson of the Haas School of Business at the University of California, Berkeley, who wasn't involved in the new research. "Most people would guess—and many interventions are built on the assumption—that knowing how smart and skilled you are benefits you in the long run. But this casts doubt on that assumption."

Rotman's graduate student Joyce He, who led the study, and Côté recruited more than 1,000 people online. Participants completed itemized tests of cognitive and emotional abilities and then reported

> **"They didn't give [subjects] self-insight and then watch what happened over time."**
>
> ***—Elizabeth Tenney***

how many items they thought they answered correctly. He and Côté recorded the actual number of items on each test and the number of items individuals thought they got right, searching for any disparities between their evaluation of their performance and how they actually did. Then, over the following week, participants filled out a daily diary survey. "We asked them to reflect on how satisfied they were with their life, with their career, with relationships in general," He says. By extending the survey over a week, she adds, she and Côté avoided the distortion that might come with someone having a particularly good or bad day.

Previous studies on self-insight had been limited, in part, by statistical techniques. Most researchers have employed "difference scores," measures of the gap between true and self-perceived ability, but they have been criticized because they conflate the original variables, which leads to ambiguous interpretations of the results. Instead He and Côté used a technique called polynomial regression, which represents a more complex statistical model that preserves the original variables. One of the benefits of the registered report process, they say, was the extensive guidance they got on how to use polynomial regression effectively. Both believe that early feedback made their paper stronger, and they are now committed fans of the registered reports approach. "It's revolutionizing the way science is done and the kind of findings people are reporting," Côté says.

It is quite possible that in the past, such a study would not have been published because the statistical analysis could not confirm what was initially proposed. As it is, the unexpected result showing that considerable self-delusion is helpful, whereas a realistic perspective is not, which He and Côté are calling "beneficial self-enhancement," must be regarded as preliminary because they hadn't put it forth as one of their hypotheses. They are at work on follow-up studies and have some early confirmatory results, but nothing has been published yet.

Moreover, even if it is confirmed that self-insight does not provide much benefit in psychological adjustment, a clear view of one's abilities might still be an important element in job performance or other areas. Psychologist Elizabeth Tenney, who studies organizational behavior at the University of Utah, doesn't think that all job reviews and student evaluations should leave out feedback on strengths and weaknesses just yet. Regarding the study, she says, "They didn't give [subjects] self-insight and then watch what happened over time." Côté agrees. "Nothing should be based on a single paper," he says.

What is clear is that registered reports allow scientists a clearer perspective on their own work. "Scientists are human," Tenney says. "We immediately will rationalize and find explanations for results. I love that [this process] ties the authors hands to do the analyses that they set out to do. This is the way science is supposed to work."

—Lydia Denworth

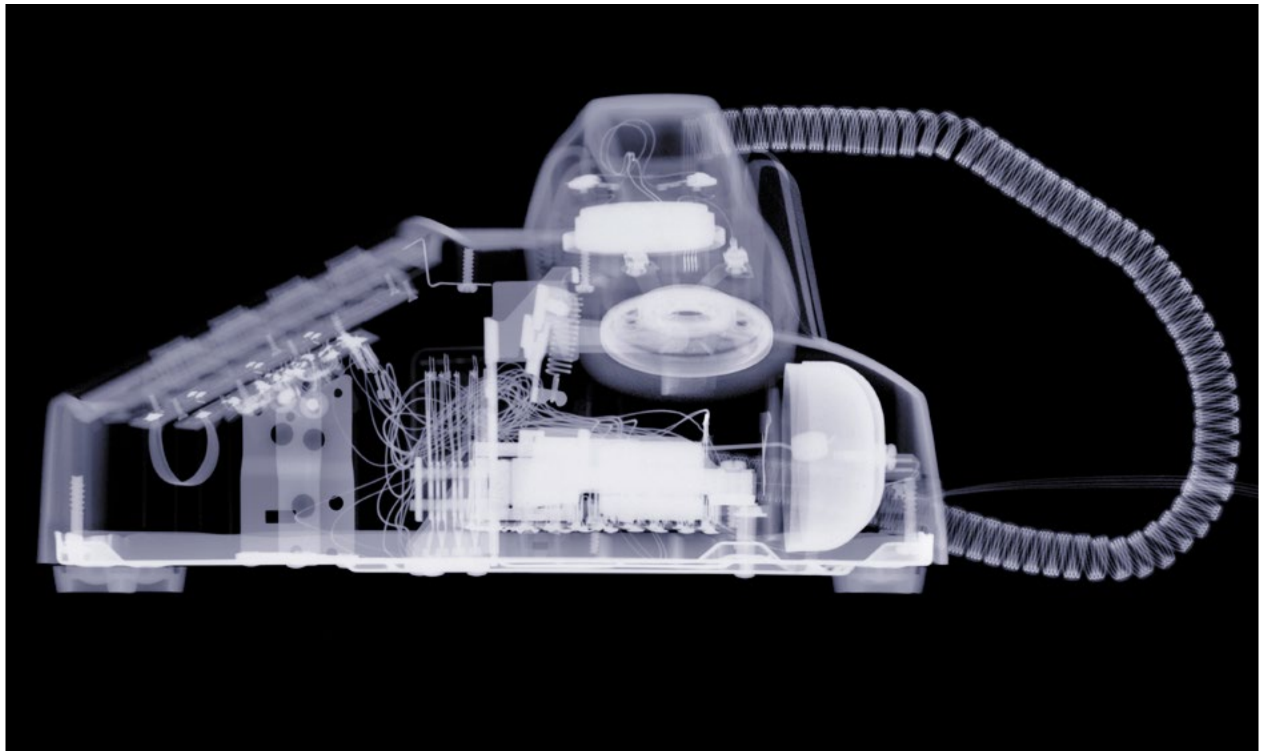
No Bones about It: People Recognize Objects by Visualizing Their "Skeletons"

This basic ability gives humans a leg up on computers

DO HUMANS LEARN the same way as computers? Cognitive psychologists have debated this question for decades, but in the past few years the remarkable accomplishments of deep-learning computer systems have fanned the flames, particularly among researchers who study object recognition.

Humans effortlessly know that a tree is a tree and a dog is a dog no matter the size, color or angle at which they're viewed. In fact, identifying such visual elements is one of the earliest tasks children learn. But researchers have struggled to determine how the brain does this simple evaluation. As deep-learning systems have come to master this ability, scientists have started to ask whether computers analyze data—and particularly images—similarly to the human brain. "The way that the human mind, the human visual system, understands shape is a mystery that has baffled people for many generations, partly because it is so intuitive, and yet it's very difficult to program," says Jacob Feldman, a psychology professor at Rutgers University.

A paper published in June in *Scientific Reports* comparing various object-recognition models came to the conclusion that people do not evaluate an object like a computer processing pixels but based on an imagined internal skeleton. In the study, researchers at Emory University, led by associate professor of psychology Stella Lourenco, wanted to know if people judged object similarity based on the objects' skeletons—an invisible axis below the surface that runs through the middle of the object's shape. The scientists generated 150 unique three-dimensional shapes built around 30 different skeletons and asked participants to determine whether or not two of the objects were the same. Sure enough, the more similar the skeletons were, the more likely participants were to label the objects as the same. The researchers also compared how well other models, such as neural networks (artificial-intelligence-based systems) and pixel-based evaluations of the objects, predicted people's decisions. While the other models matched performance on the task relatively well, the skeletal model always won.



NICK VEASEY *GETTY IMAGES*

"There's a big emphasis on deep neural networks for solving these problems [of object recognition]. These are networks that require lots and lots of training to even learn a single object category, whereas the model that we investigated, a skeletal model, seems to be able to do this without this experience," says Vladislav Ayzenberg, a doctoral student in Lourenco's lab. "What our results show is that humans might be able to recognize objects by their internal skeletons, even when you compare skeletal models to these other well-established neural net models of object recognition."

Next, the researchers pitted the skeletal model against other models of shape recognition, such as ones that focus on the outline. To do so, Ayzenberg and Lourenco manipulated the objects in certain ways, such as shifting the placement of an arm in relation to the rest of the body or changing how skinny, bulging or wavy the outlines were. People once again judged the objects as being similar based on their skeletons, not their surface qualities.

"This is top-flight work, and I was very impressed with the result," says Feldman, who was not involved in the research. "They really give empirical evidence—I would say it demonstrated more convincingly than anything I've previously seen that shape similarity is computed in the human mind via similarity of shape skeletons."

One concern with the study is that the authors generated the objects specifically from skeletons rather than deriving them from shapes, either natural or human-made, covered by skin, metal or other materials that people encounter in their day-to-day life. "The shapes that they generated are directly related to the hypothesis they're testing and the conclusions they're drawing," says James Elder, a professor of human and computer vision at York University in Toronto. "If we're interested in how important skeletons are to shape and object perception, we can't really answer that question by only looking at the perception of skeleton-generated shapes. Because obviously in a world of skeleton-generated shapes, skeletons are probably fairly important because that's the way those shapes were made."

Elder suggests that while the model may explain people's interpretation of shapes with clearly defined skeletons, such as animals or trees, it is not appropriate for all types of shapes, such as a rock or crumpled-up newspaper. Ayzenberg says that they are addressing this issue in follow-up studies using traditional shapes and naturalistic objects.

The researchers now wonder whether the skeletal model could be incorporated into deep-learning systems so that instead of exploring whether humans learn like computers, scientists could help a computer learn like a human.

"We're optimistic that it will also speak to and inform artificial neural networks that are trying to simulate human perception," Lourenco says. "There are shocking ways in which they break down that humans don't, and so being informed by how humans recognize objects is also going to be very important for them."

—Dana G. Smith

Does Birth Order Affect Personality?

Researchers examine the old adage that birth order plays a significant role in shaping who we are

IN SPITE OF sharing genes and environments, siblings are often not as similar in nature as one might think. But where do the supposed differences come from? Alfred Adler, a late 19th- and early 20th-century Austrian psychotherapist and founder of individual psychology, suspected that birth order leads to differences in siblings.

Adler considered firstborns to be neurotic because they don't have to share their parents for years and are essentially dethroned once a sibling comes along. He also considered oldest children dutiful and sometimes conservative. According to Adler, the youngest children are ambitious, while middle children are optimally positioned in the family and are characterized by emotional stability. Adler himself was the second of seven children.

American psychologist Frank J. Sulloway, who in the mid-1990s combed history books for leading figures who were firstborns and rebellious ones who were born later, saw a similar trend. Among the later borns, he found lateral thinkers and revolutionaries, such as Charles Darwin, Karl Marx and Mahatma Gandhi. Among firstborns, he discovered leaders such as Joseph Stalin and Benito Mussolini. His explanation? Every child occupies a certain niche within the family and then uses his or her own strategies to master life. Firstborn and single children had less reason to quarrel with the status quo and identify more strongly with the worldview of their fathers and mothers. Younger siblings are less sure of their parents' view and therefore more often choose alternative paths in life.

Such categorizations are popular because they're rather intuitive, and one can always find an example of the sensible big sister or the rebellious young brother in their circle of acquaintances. As such, Adler's words still appear regularly in educational guides and continue to reverberate in the minds of parents.

Furthermore, some studies confirmed the idea that sibling position

can shape personality. For example, a 1968 study showed that, compared with later borns, firstborns are less likely to participate in dangerous sports because of fears of physical injury. And a 1980 study of 170 female and 142 male undergraduates showed lower anxiety and higher ego in firstborns, as measured by the Howarth Personality Questionnaire. At times, however, these investigations used questionable methods. For example, members of the same family were often asked to assess themselves in terms of extraversion, openness to experiences, conscientiousness, tolerance and neuroticism. The catch is these surveys were conducted at only one point in time. The older siblings were therefore not only born first but also simply older. It has long been known that adolescents become more conscientious as they age. This trend could account for a large part of the results.

Another methodological flaw was that only one person judged his or her own personality and that of his or her siblings. This detail is important because self-perception and the perception of others can sometimes differ considerably. In addition, the test subjects may have subconsciously incorporated the cliché of dutiful older siblings and cosmopolitan later borns into their evaluation and could have thus brought about the expected result themselves.

Meanwhile scientists who analyzed large, transnational data and compared different families with one another have found the effect of sibling succession on personality disappears almost completely. Researchers led by psychologist Julia Rohrer of the University of Leipzig in Germany evaluated data from more than 20,000 interviewees from Germany, the U.K. and the U.S. They compared the personality profiles of siblings but also of people with different birth orders who had never met. The Leipzig psychologists did not discover any systematic differences in personality.

In such studies, researchers must be particularly cautious because, in addition to age, the size of one's family is another factor that's intertwined with sibling position. A child from a family of four has a 50 percent chance of being a firstborn; the more siblings, the lower the probability. For example, the fact that many astronauts are firstborns does not necessarily speak to the special

KRISTY-ANNE GLUBISH *GETTY IMAGES*

qualities of those born first. It's likely that many astronauts come from smaller families. To better understand these influences, Rohrer and her team controlled for the number of siblings. That's because when there are more of them, there are more later borns. So the researchers hypothesized that later borns may more often appear in families of lower socioeconomic classes—which could account for differences between children of different-sized families.

The larger the sample, the more likely even very small effects will be detected. For example, in a 2015 study, which included 377,000 high school students, psychologist Rodica Damian and her colleague Brent W. Roberts, both then at the University of Illinois at Urbana-Champaign discovered that firstborns tended to be more conscientious, extraverted and willing to lead. Contrary to expectations, they were also more tolerant and emotionally stable than adolescents with older siblings. Yet the differences were very small, and the researchers concluded that the importance that is generally attached to sibling position in shaping one's character is exaggerated.

"It is quite possible that the position in the sibling sequence shapes the personality—but not in every family in the same way," says Frank Spinath, a psychologist at Saarland University in Germany. "In other words, there may be an influence but not a systematic one. Nevertheless, other influences weigh more heavily when it comes to the differences in character of siblings. In addition to genes, the so-called undivided environment also plays a role. For siblings who grow up in the same family, this includes the respective circle of friends, for example." Further, parents do not treat their children the same regardless of their birth rank. Studies show that parents react sensitively to the innate temperament of their offspring and adapt their upbringing accordingly.

Damian's study also found that on average, firstborns enjoy a small IQ advantage over their younger siblings. Those born first also tend to complete their education with a higher degree and opt for traditionally prestigious careers, such as medicine or engineering.

How does this intellectual advantage come about? Adler may be right that the undivided attention given to the first child in early life promotes cognitive abilities. This advantage is already apparent by the age of two. Norwegian researchers Petter Kristensen and Tor Bjerkedal cleverly showed that the difference in intelligence is not linked to biological factors (some had suspected it might be related to physical conditions during pregnancy). They tested children whose older siblings had died early. The researchers' assumption was that although these children were biologically younger siblings, they would assume the role of the firstborn in the family. Compared with other younger siblings, they achieved better results in intelligence tests.

—Corinna Hartmann and Sara Goudarzi

Forget Happiness, Find Meaning

Peak emotional experiences are the most meaningful ones in our lives

By Scott Barry Kaufman

JACOB AMMENTORP LUND *GETTY IMAGES*

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WHAT DOES IT TAKE TO LIVE A MEANINGFUL LIFE? IN TRYING TO ANSWER THIS QUESTION, MOST RESEARCHERS FOCUS ON THE VALENCE OF THE LIFE EXPERIENCE: IS IT POSITIVE OR NEGATIVE?

Researchers who focus on positive emotions have amassed evidence suggesting that we are more likely to find more meaning in our lives on days when we experience positive emotions. In contrast, researchers taking a meaning-making perspective tend to focus on meaning in the context of adjustment to stressful events. These two areas of research are often treated separately from each other, making it difficult to answer the question about which valence of our emotional life—positive or negative—is most likely to be meaningful.

Both perspectives may be at least partly right. In their classic paper "Some Differences between a Happy Life and a Meaningful Life," Roy Baumeister and his colleagues zoomed in on the different outcomes associated with happiness (controlling for meaning) and meaningfulness (controlling for happiness). Whereas happiness was positively correlated with the frequency of positive events in one's life and negatively related to the frequency of negative events, greater meaningfulness was related both to a higher frequency of positive events and to a higher frequency of negative events, as well as reports of more stress, time spent worrying, and time spent reflecting on struggles and challenges. What's going on here? How can meaning be positively associated with both positive and negative experiences?

In a new paper, Sean Murphy and Brock Bastian suggest that a focus on emotional valence may have been a red herring for the field. By intentionally pitting "positive" experiences against "negative" experiences, researchers have focused on the difference between these experiences. Murphy and Bastian argue, however, that this has neglected our understanding of similarities in how the positivity and negativity of experiences are related to meaningfulness. They raise the intriguing possibility that the more relevant factor may be the extremity of the experience, not the valence. Perhaps both extremely pleasant and extremely painful events relative to more neutral events share a common set of characteristics that might lead them to be found more meaningful.

They set out to test this idea for the first time. Across three studies, they collected reports of the most significant events in people's lives across the emotional spectrum and measured the meaningfulness of the experiences. In line with their prediction, they found that the most meaningful events were those that were extremely pleasant or extremely painful.

They also looked at various qualities of the event that might explain the impact of emotional extremity on meaningfulness. They found that extreme events were found more meaningful in large part because of their emotional intensity and the contemplation they inspired (for example, "I find myself analyzing this experience to try to make sense of it"). In fact, they consistently found that positive and negative events inspired contemplation to about the same degree. While the field has focused mostly on how traumatic events inspire contemplation, this finding is in line with research looking at the rumination that often occurs after positive moods.

Their findings also point to the importance of intensity in building a meaningful life, a factor that has not received as much attention in the field as the valence of the emotion. This work is important because it ties together literatures on meaning that have often been treated separately, or even in opposition, to each other. As the researchers note, the "commonalities reveal a more complete and nuanced picture about what determines the events we find meaningful and memorable."

RETHINKING THE GOOD LIFE

Their findings have a number of important implications for our understanding of the good life as well as our understanding of human nature more generally. On the surface, it may seem perplexing that so many people intentionally behave in counter-hedonic ways, actively seeking out unpleasant experiences.

For instance, in their paper "Glad to be Sad, and Other Examples of Benign Masochism," Paul Rozin and his colleagues found that 29 initially aversive activities—including watching frightening movies, viewing sad paintings, listening to sad music, eating spicy food, listening to disgusting jokes, going on thrill rides, having a painful massage and being physically exhausted—produced pleasure in a substantial number of individuals. Rozin and his colleagues ended their paper noting that if "we had a better understanding of the function of sadness, we would no doubt be able to make more sense of this."

Yet the findings of Murphy and Bastian suggest that it is not the sadness per se that is enjoyable but the intensity of the experience that is enjoyable because it leads to a greater sense of meaning. This makes sense from a narrative identity perspective: our life story and our sense of who we are is a carefully constructed selection of meaningful events from our lives. The events that we find most worthy of incorporating into our life story may be those that are most intense. The greater contemplation associated with intense experiences may increase the likelihood that we consider such events self-defining.

More than 50 years ago Abraham Maslow talked about the importance of "peak experiences," which he described as "rare, exciting, oceanic, deeply moving, exhilarating, elevating experiences that generated an advanced form of perceiving reality, and are even mystic and magical in their effects." While people often talk about the euphoria of peak experiences, Maslow often pointed out how overcoming intense challenges and setbacks can be a key trigger for a peak experience.

Similarly, in his 2018 book *The Other Side of Happiness: Embracing a More Fearless Approach to Living*, Bastian argues that suffering and sadness are actually necessary ingredients for happiness. He notes that "the most thrilling moments in our lives are often balanced on a knife edge between pleasure and pain.... Our addiction to positivity and the pursuit of pleasure is actually making us miserable ... without some pain, we have no real way to achieve and appreciate the kind of happiness that is true and transcendent." Yale University psychologist Paul Bloom has also been making sense of the "pleasures of suffering."

These findings have implications for the mindfulness craze and provide a much needed counterpoint to the current trend of viewing calm and tranquil experiences as most conducive to a life well lived. To be sure, mindfulness, meditation and cultivating inner calm can be beneficial for reducing anxiety, improving depression and helping us cope with pain.

Still, the intensity of peak experiences may be more likely to define who we are. At the end of our lives, will we look back and remember most poignantly all of the calm and tranquil meditation sessions we had, or will we remember the moments that plumbed the depths of our emotional life, that made us feel most alive?

Embracing Our Fear

It's a hardwired response, but it doesn't have to rule our emotions

By Dean Mobbs, Ralph Adolphs, Michael S. Fanselow, Lisa Feldman Barrett, Joseph E. LeDoux, Kerry Ressler and Kay M. Tye

ARJO VAN TIMMEREN *GETTY IMAGES*

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Lisa Feldman Barrett is a neuroscientist at Northeastern University and Harvard Medical School.
Joseph E. LeDoux is a neuroscientist at New York University.
Kerry Ressler is a neuroscientist at McLean Hospital in Boston and Harvard Medical School.
Kay M. Tye is a neuroscientist at Salk Institute for Biological Studies in La Jolla, Calif.

What is fear?

The answer seems simple, yet a vigorous debate concerning its meaning has been playing out over the vista of affective neuroscience. This debate has a long history, but it was recently reignited by Joseph E. LeDoux, who proposed that we should not only redefine fear but also change the way we experimentally investigate this emotion. At the core of this debate lies the view that emotions are conscious, subjective states. For example, feelings related to fear, such as horror or terror, are cognitively assembled conceptions of one's situation, rather than preformed, innate mental states inherited from animals. LeDoux thus argues such complex states of the human brain cannot be studied in animals. Instead he proposes that "defensive survival circuits" that underlie defensive behaviors be the focus of research in animals. These hardwired circuits are proposed to be orthogonal to subjective fear states that presumably involve higher-order circuits—they can modulate but do not determine the emotion. An equally provocative theory is Lisa Feldman Barrett's theory of constructed emotion, which proposes that the human brain constructs instances of fear as a consequence of predicting and inferring the cause of incoming sensory inputs from the body (that is, interoceptive and somatosensory inputs) and the world (that is, exteroceptive inputs). Barrett proposes that a brain is continually projecting itself forward in time, predicting skeletomotor and visceromotor changes and inferring the sensory changes that will result from these motor actions. Probably most controversial about Barrett's theory is that it proposes that fear, like other emotion categories, does not have a hardwired neuroanatomical profile but is part of a dynamic system in which prediction signals are understood as ad hoc, abstract categories or concepts that are generatively assembled from past experiences that are similar to present conditions. In this view, the brain is a categorization machine, continually creating contextually relevant concepts that are appropriate to an animal's niche.

These thought-provoking views seem to go against other prominent views, such as the basic (or primary) fear circuits theory of the late Jaak Panksepp and other celebrated luminaries in the field (for example, Michael Davis, Robert Bolles, O. Hobart Mowrer). For example, Ralph Adolphs emphasizes the universality of defensive behaviors, which adds credence to the view that fear circuits are mirrored across species and therefore partly innate. Michael S. Fanselow proposes that fear (and anxiety) can be placed along a threat-imminence continuum, which acts as a general organizing principle, and where threat intensity can be linked to motivational processes and defensive behaviors. Likewise, Kay M. Tye suggests that fear is a negative internal state that drives and coordinates defensive responses. These views see defensive behaviors as the manifestation of hardwired fear (or survival) circuits and are controlled and modified by cognitively flexible circuits. While this debate has begun to wash up on the shoreline of clinical science and practice, there is still much needed agreement between the fields of basic and clinical science on how to define and investigate fear and anxiety. Here we asked some of the most influential contemporary scientists to discuss their perspective. Covering both human and animal research, each will present one argument for each of the discussion points below.

Q1: Dean Mobbs (moderator): How do you define fear, and how is your definition supported by neuroscience?

Ralph Adolphs (RA): Fear can only be defined based on observation of behavior in a natural environment, not neuroscience. In my view, fear is a psychological state with specific functional properties, conceptually distinct from conscious experience; it is a latent variable that provides a causal explanation of observed fear-related behaviors. Fear refers to a rough category of states with similar functions; science will likely revise this picture and show us that there are different kinds of fear (perhaps a dozen or so) that depend on different neural systems.

The functional properties that define the state of fear are those that, in the light of evolution, have made this state adaptive for coping with a particular class of threats to survival, such as predators. Fear has several functional properties—such as persistence, learning, scalability and generalizability—that distinguish emotion states from reflexes and fixed-action patterns, although the latter can of course also contribute to behavior.

The neural circuits that regulate an animal's fear-related behavior exhibit many of these same functional properties, including in the mouse hypothalamus. They are initial evidence that this brain structure is not merely involved in translating emotion states into behaviors but plays a role in the central emotion state itself. Neuropsychological dissociations of fear from other emotions show that fear is a distinct category.

Michael Fanselow (MF): Fear is a neural-behavior system that evolved to protect animals against environmental threats to what John Garcia called the external milieu (as opposed to the internal milieu), with predation being the principal driving force behind that evolution (for example, as opposed to a toxin). This is the organizing idea behind my definition of fear. The complete definition must also include the signals giving rise to fear (antecedents) and objectively observable behaviors (consequents). The neuroscientific support for this definition is that many signals of external threat, such as cues signaling possible pain, the presence of natural predators and odors of conspecifics that have recently experienced external threats, all activate overlapping circuits and induce a common set of behaviors (for example, freezing and analgesia in rodents). Equally important as neuroscientific support is support from fieldwork, which has repeatedly shown that behaviors such as freezing enhance survival in the face of predators.

Lisa Feldman Barrett (LFB): I hypothesize that every mental event, fear or otherwise, is constructed in an animal's brain as a plan for assembling motor actions and the visceromotor actions that support them, as well as the expected sensory consequences of those actions. The latter constitute an animal's experience of its surrounding niche (sights, sounds, smells, and so on), including the affective value of objects. Here value is a way of describing a brain's estimation of its body's state (that is, interoceptive and skeletomotor predictions) and how that state will change as the animal moves or encodes something new. The plan is an inference (or a set of inferences) that is constructed from learned or innate priors that are similar to the present conditions; they represent the brain's best guess as to the causes of expected sensory inputs and what to do about them.

The function most frequently associated with fear is protection from threat. The corresponding definition of fear is an instance an animal's brain constructs defensive actions for survival. A human brain might construct inferences that are similar to present conditions in terms of sensory or perceptual features, but the inferences can also be functional and therefore abstract, and thus they may or may not be initiated by events that are typically defined as fear stimuli and may or may not result in the behaviors that are typically defined as fear behaviors. For example, sometimes humans may laugh or fall asleep in the face of a threat. In this view, fear is not defined by the sensory specifics of an eliciting stimulus or by a specific physical action generated by the animal; rather it is characterized in terms of a situated function or goal: a particular set of action and sensory consequences that are inferred, based on priors, to serve a particular function in a similar situation (for example, protection).

In cognitive science, a set of objects or events that are similar in some way to one another constitutes a category, so constructing inferences can also be described as constructing categories. Another way to phrase my hypothesis, then, is that a brain is dynamically constructing categories as guesses about which motor actions to take, what their sensory consequences will be, and the causes of those actions and expected sensory inputs. A representation of a category is a concept, and so the hypothesis can also be phrased this way: a brain is dynamically constructing concepts as hypotheses about the causes of upcoming motor actions and their expected sensory consequences. The concepts or categories are constructed in a situation-by-situation manner, so they are called ad hoc concepts or categories. In this way, biological categories can be considered ad hoc conceptual categories.

Joseph LeDoux (JL): I have long maintained that conscious emotional experiences are, like all other conscious experiences, cognitively assembled by cortical circuits. Fear, for example, is a conscious awareness that you are in harm's way. Activation of subcortical circuits controlling behavioral and physiological responses that occur at the same time can intensify the experience by providing inputs to the cognitive circuits, but they do not determine the content of the experience. The experience itself, in my model, is the result of pattern completion of one's personal fear schema, which gives rise to some variant of what you have come to know as one of the many varieties subsumed under the concept of "fear" that you have built up by accumulating experiences over the course of your life. Fear can even occur when some or all of the subcortically triggered consequences are absent: when the threat alone generates memory-based expectations that mentally simulate the missing elements, there-by pattern-completing your fear schema. Fear is often said to be universal. But instead what is universal is danger. The human experience of being in danger is personal and unique. While other animals may have some kind of experience when in danger, it is not possible to scientifically measure what they experience, and if we could, it is unlikely it would be equivalent to the kind the of cognitively assembled personal awareness of being in harm's way that humans experience. Such a cognitive account would seem necessary to explain, in one framework, the variety of threatening situations in which one can consciously experience fear (for example, predatory, conspecific, homeostatic, social, existential).

Kerry Ressler (KR): My definition of fear is one that is pragmatic and clinical, perhaps a "functionalist" definition from Adolphs's perspective. "Fear" is the combination of defensive responses—physiological, behavioral and (perhaps in the case of humans) the conscious experience and interpretations of these responses—that are stimulated by specific stimuli. In the case of experimental systems, these stimuli are external cues but presumably in humans can have internal representations as well (thoughts and memories that can be fear-inducing cues themselves). Such fear-inducing cues result in active defensive responses that gradually subside when the stimulus is no longer present. Clinically, fear can be thought of as mirroring the response to a specific cue (for example, the fear of snakes); anxiety is a more long-lasting phenomenon that may not be specific to overt cues. Decades of preclinical neuroscience studies examining mechanisms of Pavlovian fear or threat conditioning have, in conjunction with human neuroimaging work, indicated the involvement of multiple brain regions in communication with the amygdala and its downstream connections in support of the "hardwired" regulation of subcortical and brain stem areas mediating the cardiovascular, respiratory, autonomic nervous system, hormonal, startle, freezing and other behavioral "fear" or "threat" reflexes.

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Kay Tye (KT): Fear is an intensely negative internal state. It conducts orchestration of coordinated functions serving to arouse our peak performance for avoidance, escape or confrontation. Fear resembles a dictator that makes all other brain processes (from cognition to breathing) its slave. Fear can be innate or learned. Innate fear can be expressed in response to environmental stimuli without prior experience, such as that of snakes and spiders in humans and to predator odor in rodents. Fear associations—primarily studied in the context of Pavlovian fear conditioning—are the most rapidly learned (one trial), robustly encoded and retrieved, and prone to activate multiple memory systems. Given its critical importance in survival and its authoritarian command over the rest of the brain, fear should be one of the most extensively studied topics in neuroscience, although it trails behind investigation of sensory and motor processes because of its subjective nature. Watching others exhibit the behavioral expressions and responses of fear may invoke emotional contagion or support learning about the environment. The usage of the term "fear" in the field of behavioral neuroscience has taken on a related—but distinct—meaning through the extensive use and study of a very stereotyped behavioral paradigm originally termed "fear conditioning." Fear conditioning is arguably the most commonly used behavioral paradigm in neuroscience and has been most comprehensively mined in terms of neural circuit dissection with rodent models but has also been used in humans, primates and even invertebrates. Fear conditioning refers to the Pavlovian pairing of a conditioned stimulus (most often an auditory pure tone) with a foot shock that is most often presented on the termination of the conditioned stimulus.

Q2: How does your theory of fear separate neural circuits for feeling, perception and action?

RA: I don't claim to have a theory, but in my view fear, feeling, perception and action are all distinct. Fear causally interacts with many other processes, including perception, action planning, attention, memory and others. But it is distinct in that we can manipulate fear independently of many other cognitive variables. Losing perception, as in blindness, doesn't make you lose fear, merely the ability to induce it visually; losing all behavior, as when paralyzed, also doesn't make you lose fear; similarly for memory and other processes. It is important to note that a state of fear by itself does nothing: it needs to connect with all these other processes to result in behavior (as is the case for perception, attention, and so on, themselves). Most important is the distinction between feeling fear (the conscious experience of fear) and the functional state of fear (the state that explains all the effects a threatening stimulus has on cognition and behavior). I'm agnostic about how these are related, but I think for methodological reasons, for example, the ability to study fear in nonhuman animals, we need to keep them conceptually separate. It is also very difficult to distinguish the neural correlates of feeling fear and the functional state of fear. All of the above suggest some cognitive architecture defined by constitutive and causal relations between processes. How this is actually neurally implemented no doubt varies between phyla and classes; fear in an octopus will have very different neural details than fear in a human or a rat.

MF: It doesn't. The relevant circuit integrates them; perception of threat leads to feelings and to actions. Activation of the fear state also feeds back on perceptual systems, altering how they react to environmental stimuli. The perception of threat is a critical determinant of both the magnitude of fear and the topography of defensive behavior. Note that not all actions stem from feelings, but all fear-related feelings lead to some change in action. If they didn't, they would lose biological meaning and, to the extent that feelings require energy, they would be eliminated by evolution. A complete circuit connects and integrates these components into effective defensive patterns.

LFB: In my view, this is not the optimal question to ask about fear, because it rests on an unfounded assumption that the brain is best understood as collections of neurons, grouped together in anatomically separate systems (neural circuits) for perceptions, mental events, feelings and various types of action (for example, freezing, running), which pass information back and forth to one another like a baton in a relay race. My research approach is guided by the alternative assumption that the brain should be understood as a complex dynamical system that is composed of elements: circuits or subnetworks made of neurons and supporting glial cells. These elements do not function independently of one another, because their arrangement and organization change dynamically. Even the neurons that constitute change dynamically. The brain, as a dynamical system, is continuously traversing through a succession of events, referred to as its state space, which is specified as values for a set of features that describe the system's current state. Features are physical (for example, neural, physiological, chemical) and mental (perceptual, affective, cognitive, and so on). In this view, the brain works by prediction and correction rather than through stimulus and response. Within the dynamics of a particular state of the system perceptions are the result of motor preparation, rather than the other way around (as suggested by a stimulus-response approach).

JL: In my scheme, fear is the feeling of being afraid. I would refer to perception and action in this context as threat detection and defensive responding. I view the experience of fear and behavioral reactions as separate consequences of threat detection and mediated by different but interacting circuits. Threat detection obviously starts with sensory processing, research on which is informative in illustrating the relations among stimulus processing, behavior and experience. For example, studies of visual perception in patients with blindsight show that the path to conscious perceptual experience can be dissociated from the path to behavior. This suggests that the correlation of perceptual experience with behavior in healthy brains may be the result of parallel processing of sensory information by different systems and does not necessarily mean that the experience and behavior are entwined in the brain. Perceptual researchers thus tend to be cautious when extrapolating from behavioral responses to experience. In terms of fear, blindsight is again informative. These patients respond to threats but do not report awareness of the threat stimulus or conscious feelings of fear; self-report of conscious feelings in such patients correlates with neocortical activity. Similarly, in subliminal-stimulation studies of healthy humans, threats activate subcortical defensive circuits involving the amygdala and elicit physiological responses in the absence of stimulus awareness; feelings are not reported even when specifically asked about. The circuits that control behaviors that are only sometimes correlated with fear experiences are thus not necessarily the circuits that underlie the experiences. When we label these circuits and behaviors with the term "fear" we propagate conceptual confusion.

KR: I think that we can, at a neuroscience level, make some distinctions among the sensory components (for example, sensory thalamus and cortex: feeling); integrative cognitive components (for example, associative cortex and medial prefrontal cortex: perception); and reflexive and behavioral components (for example, amygdala, striatum, brainstem: action). But how these distinct circuits map upon conscious versus behavioral aspects of fear processing may be more difficult to parse. Progress in dissecting the neural connections of fear and threat has contributed to our understanding of how they regulate the autonomic, physiological and behavioral activity patterns that together make up the fear reflex, which appears to be highly conserved across species. Some aspects of these different components are clearly represented in similar areas—for example, medial prefrontal cortex and amygdala activation are seen with threat perception in humans but are also clearly involved in actions underlying threat behaviors across species—whereas other regions, for example, brain stem nuclei, may be involved primarily in the action component of the fear process.

KT: Initial information flow arrives via sensory inputs that propagate to limbic circuits (for example, amygdala), which then feeds forward to downstream targets (for example, striatum, basal ganglia), where emotional states combine with threat imminence to promote action selection. Limbic signals can then feed back onto the sensory systems to alter perception. Fear itself does not map onto an individual motor output; it is an intermediate process that links sensory processing to action selection.

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My current conceptual model consists of three psychological processes that determine importance (or salience), valence and action, respectively. These three processes are mediated by different circuits. For example, if a grazing deer hears a twig snap, it must initially assess the importance of the stimulus. If it is in a clear landscape with nowhere for a predator to hide, then the stimulus may be deemed unimportant and the deer may go on grazing. If the deer sees a familiar conspecific, then it may interpret the stimulus as a positive valence signal, prompting selection of agonistic social behavior or approach. If there is dense brush, then the potential threat of a predator signaled by the stimulus may trigger an internal state of fear.

Given a fear state, the outcome depends heavily on threat imminence. For example, if the predator is far away or its location is unknown, it may be most adaptive to hide or freeze to avoid detection by the predator. If the predator is at an intermediate distance where detection is likely or has already happened, then escape may be the best strategy. If the predator is mounting an attack, then defensive behavior to fight off the predator may be the best response.

Q3: Are there different defensive circuits (for example, predatory versus social, survival circuits, reactive versus cognitive fears), and if so, are they orthogonal or synergistic? What is the evidence for your position?

RA: Yes, I think there is very good evidence that there are neural circuits specialized for subtypes of fear. Fear is not one thing. For instance, a circuit involving the superior colliculus and periaqueductal gray has been dissected in some detail for mediating fear behaviors elicited by the sight of aerial predators in rodents. Conversely, the ventromedial hypothalamus has cell populations that participate in states of fear and respond to sounds or odors of conspecifics but not to aerial predators. There are also different circuits relating to threat imminence (anxiety, fear, panic). Work in humans with amygdala lesions has dissociated fear of teloreceptive stimuli (snakes, spiders, and so on) from fear of interoceptive stimuli (for example, suffocation). To the extent that different types of threat require different adaptive behaviors, they would constitute different functional states—and this functional specialization should be reflected in the neural circuits. These relatively dedicated neural circuits for subtypes of fear are subcortical, whereas cortical involvement is most likely to feature mixed selectivity, such that the same cortical neurons can encode the multiple actions that might need to be taken in an adaptive response to fear, depending on the circumstances.

MF: Yes. For example, the taste aversion-disgust-toxin avoidance system (Garcia's internal milieu defense) is distinct from predatory defense (external milieu). In a nice demonstration of this, Bernstein's lab showed that within the basolateral amygdala, taste (conditioned stimuli) and toxin (unconditioned stimuli) converge on different sets of neurons than contextual conditioned stimuli and shock unconditioned stimuli. This illustrates the common error of considering the basolateral amygdala as isomorphic with fear. It is not; it mediates several aversive and appetitive motivational systems that involve different cells and microcircuits within the amygdala. Another concern about purely amygdalocentric views is that not all antipredator defensive modules are equally dependent on the amygdala. For example, I proposed a circa-strike-panic defensive module that depends more on the periaqueductal gray than amygdala. This model anticipated the finding that CO_2-induced panic occurs in a patient with bilateral loss of the amygdala who otherwise is severely deficient in fear reactions. Interactions between different aversive systems, much like interactions between appetitive and aversive systems, are often inhibitory because the systems serve different functions and one function may need to take precedence over another; for example, inhibition of the pain or recuperative system via analgesic circuitry is part of the fear and defense system. But there is also convergence. In rodents, defense against predators (interspecies) and alpha males (conspecifics) activates very similar brain structures and behaviors, suggesting that there was substantial convergent evolution of these defenses. One reason my essay provides for a rich (six-part) definition of fear is to help distinguish fear from other systems.

LFB: Neuroscience research on motor control has revealed that motor actions are not triggered by simple, dedicated circuits but are assembled within a flexible neural hierarchy whose motor modules are in the spinal cord. I hypothesize that the same may be true for visceromotor actions. In this view, attempts to build taxonomies of simple defensive circuits are not scientifically generative. The presence of flexible neural hierarchies means that each behavior—such as freezing, fleeing and fighting—is not the result of one specific circuit but instead may be implemented in multiple ways. In my view, a brain, as a single dynamical system, has the core task of regulating skeletomotor actions as well as visceromotor actions within the body's internal milieu that supports those actions. This idea suggests that there are degenerate assemblies for each behavior, even in the same situation. Furthermore, the neurons that process sensory inputs (for example, in V1, primary interoceptive cortex) and the neurons that represent affective value all function in the service of actions and carry information about those actions and therefore are part of the flexible hierarchy for action control.

JL: Nathaniel Daw and I recently proposed taxonomy of defensive behaviors and their neural underpinnings that might provide an organizational framework for considering some of the diverse levels of analysis implied in the present question. Included are reflexes, fixed reactions, habits, action-outcome behaviors and behaviors controlled by nonconscious and by conscious deliberation. For example, species-typical responses to predatory and social cues can be thought of as fixed reactions that are "released" when different, but to some extent overlapping, subcortical survival circuits are engaged. Also relevant are circuits that signal challenges to survival, monitor homeostatic imbalances and initiate restorative behaviors. Instrumental, habitual behaviors are fixed but have to be learned and involve corticostriatal circuits, whereas action-outcome instrumental behaviors are learned but flexible and use different corticostriatal circuits. Deliberative instrumental responses are prospective and model-based, and they engage prefrontal circuits; here nonconscious deliberation about danger allows rapid mental simulation of possible solutions, whereas in slower conscious deliberation, the experience of fear can guide future planning and action.

KR: For brevity, I will focus on the amygdala, which is actually a complex of several cell clusters (nuclei) and is conserved from the most primitive mammals and in most vertebrates. It receives neural projections from essentially all sensory areas of the brain, as well as from memory-processing areas in addition to association and cognitive brain regions. It sends projections back to many of these areas but. most interestingly, also communicates with an array of brain stem and other subcortical areas. Notably, all of these circuits are involved in both defensive and appetitive behaviors, not to mention predatory versus social behaviors, and so on. Recent fascinating work has shown that even within the same subregion of the amygdala, neighboring cells can have opposing functions or more nuanced functional differences; for example, they may respond preferably to proximal versus distal threats. Such findings suggest that parallel information pathways, for example, different cells encoding "fear-on" versus "fear-off" information, flow through basolateral and central amygdala nuclei. Furthermore, the same cells that "turn off" a fear response may be responsible for activating positive emotions, such as appetitive or even addictive behavior. Thus, these information channels may be better appreciated as underlying approach versus avoidance related behaviors and drives. It is also possible, however, that as such behaviors are parsed at a neural circuit level, they won't match well onto our historic terminology of defensive circuits as outlined.

KT: Synergistic. Everything is connected in the limbic system, if not through direct reciprocal connections, then through neuromodulatory systems. Circuits that mediate different types of fear are likely to converge onto some common pathways, before diverging again for action selection. For example, animals can learn to fear an environmental stimulus through firsthand experience but also through observing others. We know that the basolateral amygdala (BLA) is a critical nucleus for translating sensory information into motivational significance for associations learned through direct experience and that observational fear learning requires both the BLA and the anterior cingulate cortex. The anterior cingulate cortex's role is to interpret the demonstrator's distress and send this signal to the BLA, where associative learning takes place.

Q4: How does (or can) your perspective fit with the others' perspectives?

RA: My functional emphasis is probably closest to the views of Mobbs and Fanselow. I particularly like threat imminence theory, which is of course a functional theory. My view of fear as a state that is distinct from the conscious experience of fear seems aligned with LeDoux's view with respect to that emphasis. This is a bit ironic, since I disagree with LeDoux's conclusions (he redefines fear to mean the conscious experience of fear), but I think he has written most clearly about the distinction, which is important. I would actually reinterpret his view as being about how we recognize that an organism is in a state of fear. We recognize this state in ourselves by having a conscious experience of fear; we recognize it in other people from their verbal reports or behavior; and we recognize it in animals from their behavior. If we want to be consistent, we should apply whatever meaning of fear to both other humans and to animals, since the evidence is of the same type. Ressler's and Tye's views stay closer to the neurobiology, and I certainly share the view that a lot of questions about fear are empirical matters, mostly still needing resolution. There is no question that the science of fear, even in the absence of any agreement on conceptual or theoretical issues, will make progress and indeed will inform the conceptual and theoretical issues. I would agree that it's productive to just get on with the neuroscience even without agreement about the philosophical issues, but I also think we need to continue to take stock and discuss the philosophical issues to get a sense of where we're heading. Feldman Barrett's view both shares some strong agreement with mine and is completely opposed. I share her emphasis on the context-dependency of emotions and, in particular, her attack on the notion that we can "read out" emotions from facial expressions (indeed, we just co-authored a paper on this). But I disagree with her notion that there are no objective criteria to decide whether an animal or person is in an emotion state or in a particular type of emotion state.

MF: Like Adolphs's approach, my approach emphasizing evolutionary demands is a take on functionalism; indeed, my first paper on predatory imminence was entitled "A Functional Behavioristic Approach to Aversively Motivated Behavior." I resonate completely with Adolphs's sentiment that "emotions are states of an organism that are defined by what they do." I note that both Adolphs and LeDoux are critical of behavioristic approaches, but their criticism is leveled at radical behaviorism. My behaviorism is a product of Tolman's cognitive behaviorism that emphasized purpose in behavior, although Tolman was more focused on immediate or proximal function (How do I get food here?) as opposed to ultimate function (Why do I seek food?). Indeed, fear-related actions were phylogenetically programmed because they had a high probability of success over many generations, but the actions may be maladaptive in an immediate situation. This also means that any individual instance of these programmed behaviors may not be effective in the current situation. That is why any particular instance of fear behavior may seem, and actually be, irrational in the present moment.

My approach appears to be in direct contradiction with both Feldman Barrett and LeDoux's ideas that fear is entirely a higher-order conscious construction. The adaptive function of consciousness is typically viewed as providing flexibility and supporting deliberative, proximally rational, behavior. I think this stands at odds with the necessary features of life in the face of threat. Reactions have to be immediate; any time spent in deliberation increases the likelihood of death. Therefore, these fear reactions are phylogenetically programmed responses. When faced with a predator, there is no time to acquire behaviors based on trial and error and no time for novel planning. The contrast with Tolman is again instructive. Tolman emphasized variable means to fixed ends; if you have a cognitive map that reveals the location of food, the animal may use many different ways of getting to that food. The idea is quite similar to Feldman Barrett's description of one-to-many mapping in motor systems. But Tolman's theory was based on empirical work with a food reinforcer, where considerable flexibility is not only tolerated but beneficial: you don't die if you miss one meal, and trying out something new may lead to a richer patch or a nutrient unavailable in the preceding meal. The demands of defense are entirely different. Hence, the rodent's most studied food-getting response, lever pressing, is virtually impossible to investigate in the frightened rat.

> **My scientific approach differs substantially in its guiding ontological commitments than those that guide current research on the nature of fear.**
> *—Lisa Feldman Barrett*

LFB: Empirically, the scientific findings constitute a small subset of what remains to be discovered about the neurobiological basis of fear. My scientific approach differs substantially in its guiding ontological commitments than those that guide current research on the nature of fear.

JL: Each of the participants has laid out a cogent argument for their position. I enjoyed reading the essays, and I learned something new about what each author thinks. My ideas about the conscious experience of fear overlaps with Feldman Barrett's, as we both view fear as a cognitively assembled state that is based on mental models and conceptualizations of situations. For me, the other factors or ingredients that contribute to fear, such as brain arousal and feedback from body responses, modulate but do not determine the quality of the experience. On the other hand, my ideas about the role of brain areas such as the amygdala in detecting threats and initiating body reactions and on the role of resulting motivational states that guide instrumental actions are largely compatible with the views of the other contributors. Much of what we disagree about is semantic—in the presence of a threat, is fear the experience itself or all of the various consequences triggered by the threat? But to say the differences are semantic does not mean they are unimportant. Words are powerful. They underlie our conceptions and shape the implications of our theoretical points of view, and they influence what others conclude about our research. We should do our best to eliminate ambiguity and confusion in our scientific word choice. Our lexicon provides us ways to do this, and we should make use of the subtlety of our language when we use it scientifically. An easy way to start is to avoid using mental state terms to describe behaviors that are not based on mental states. In humans we can make these distinctions and should then avoid using mental state terms to describe behavior in animals when in humans similar responses are not controlled by subjectively experienced mental states. I believe that words like threatening stimuli, defensive responses and defensive survival circuit characterize stimulus-response relations in animals better than fear stimuli, fear circuits and fear responses.

KR: In most ways, I agree with the other perspectives, in that I feel everyone is stating similar aspects of a broader shared understanding, but with nuanced differences. I think my perspective is most focused on the observation that in human neuropsychiatry research, the science of aversive behavior and fear-related disorders, along perhaps with appetitive behavior and addiction, is the most mature for clinical translation. Specifically, I agree with Adolphs's idea that a "functionalist view of emotions like fear requires an interdisciplinary approach." I agree with Fanselow's defining characteristics of fear—a formalistic approach that I believe has much utility, in particular with regard to the differential experiential states that distinguish different functional modes between anxiety, fear and panic. I agree with Feldman Barrett that the features of fear "include some set of physical changes (autonomic nervous system changes, chemical changes, actions, and so on) and sensations that become perceptions of the surrounding world and the body." I agree with LeDoux that "fear is a conscious experience in which you come to believe that you are about to be harmed" and with Tye on the importance of a conceptual model consisting of "three psychological processes that determine importance (or salience), valence and action, respectively."

While I also agree with many of the nuanced, philosophical, psychological, behavioral and neuroscience-based definitions, I don't want to lose sight of how much progress has been made and how powerful the concept of fear is to translational neuropsychiatry.

The contemporary assays are seriously flawed in that they compare apples and oranges between studies in animals and studies in humans.
—Ralph Adolphs

Q5: Do current behavioral assays for the study of fear restrict our ability to improve our understanding of fear?

RA: The contemporary assays are seriously flawed in that they compare apples and oranges between studies in animals and studies in humans. There are quite a number of behavioral assays for fear in animals, essentially none of which are used in studies in humans, which instead typically use verbal reports as the ground truth. Since it's impossible to use verbal reports in animals, the solution seems in principle straightforward: we need to adapt the behavioral batteries from animal studies to studies in humans. Only a few studies have attempted this. An additional challenge of course is ecological validity. Mobbs's study of moving a tarantula closer and closer to your foot while you are in the scanner is a rare but classic success in this direction. The problem also extends to the stimuli used. There are many studies that present human subjects with facial expressions of emotions or that have them read short vignettes. Those studies may show something about social perception or people's semantic knowledge about the concept of fear, but they do not assess the actual state of fear.

I am quite concerned about the inadequacy of most experimental protocols to study human fear, which have disconnected the study of fear in humans from the study of fear in animals. Human studies need more ecologically valid stimuli and better behavioral assays, in particular ones that do not rely on verbal reports and that can be argued to have some homology to the behavioral assays used in animal studies.

MF: Pavlovian fear conditioning is a natural component of how prey recognize predators, and it works great in the lab. But its success comes with dangers. One of these dangers is that it has led to disproportionate emphasis on one module in the threat continuum (postencounter fear), and our knowledge of the other components (circa-strike panic and preencounter anxiety) lags behind. Perhaps an even greater danger is the tendency to treat procedure as isomorphic with process.

Procedurally, fear conditioning is defined as pairing a neutral stimulus with an aversive one, but this procedure will not invariably condition a fear state, because not all aversive stimuli support engagement of the antipredator defensive system. A toxin is clearly an aversive stimulus, but pairing a neutral flavor with a toxin leads to palatability shifts that reduce consumption and not an antipredator defense. Likewise, some shocks are sufficiently novel and powerful to condition fear, but others are not; a mild shock may well be annoying but insufficient to condition fear. A rat's behavior is more flexible with a very weak shock, but that flexibility is progressively lost as shock intensity increases. I take this loss of behavioral flexibility as diagnostic of a fear state. Therefore, one must be cautious when choosing shock intensity or letting subjects choose shock intensity. Additionally, other commonly used outcomes in human fear studies, such as loss of money, are unlikely to tap into the neural systems that support antipredator defense.

When a scientist observes actions and infers an instance of fear, the scientist is engaging in emotion perception.
—Lisa Feldman Barrett

LFB: Contemporary paradigms, guided by the notion of simple, dedicated neural circuits for fear arranged in a single taxonomy, restrict the study of fear in several important ways. First, instances of fear are typically studied in laboratory settings that differ strongly from the ethological contexts in which they naturally emerge. All potential actions have an energy cost, and an animal's brain weighs these against potential rewards and revenues in a particular context. Economic choices about actions, therefore, are necessarily influenced by a number of situation-specific considerations about an animal's state and the state of the environment, most of which are held constant in the typical laboratory experiment. These factors influence not only which defensive action is executed (as suggested by some taxonomies of defensive behaviors), but also how any given action is implemented. Ignoring these factors make the neural causes of defensive actions seem more atomistic than they actually are, and as a consequence, most contemporary paradigms are insufficiently holistic (see my answer to Question 2). Second, contemporary paradigms confound things that should be kept separate. For example, it's important to distinguish affect and emotion. Affective features such as valence and arousal are best thought of as low-dimensional summaries of higher-dimensional interoceptions that result from allostasis; valence and/or arousal might be intense during episodes of emotion but are not specific to those episodes. Because allostasis and interoception are continually ongoing in an animal's life, valence and arousal are mental features that may describe every waking moment of that life. For this statement to make sense when comparing human and nonhuman animals, it is necessary to distinguish a brain's capacity for consciousness (an experience) and its capacity for awareness (the ability to report or reflect on an experience); relatedly, it is important to distinguish perceiving the sensory features of the immediate context in a particular way from being aware of that perception (for example, an awareness of perceiving threat) and from the awareness of being frightened. It's also important not to confound a threatening stimulus with the context in which the threat emerges, as often occurs in taxonomies of fear. Brains don't perceive stimuli; they perceive sensory arrays—that is, stimuli in context.

And perhaps most important, one should not confuse observation and inference. Scientists measure things like skeletomotor actions (such as freezing) and the visceromotor actions that support those skeletomotor actions (such as changes in heart rate), which they might refer to as fear; correspondingly, they measure the change in neural firing that supports those actions, which they might refer to as fear circuitry. This approach confounds what is observed (for example, freezing, changes in heart rate) with their inferred cause (for example, fear). The science of fear would be more productive and more generative if the two were not routinely confused.

When a scientist observes actions and infers an instance of fear, the scientist is engaging in emotion perception. Fear is always a perception—an inference—whether on the part of a scientist observing an animal's actions, a human observing another human's actions, or an animal making sense of its sensory surroundings as part of action control. No changes in the autonomic nervous system or skeletomotor actions are, in and of themselves, meaningful as fear. A brain makes them meaningful as fear with inferences (which can also be described as prediction signals or ad hoc concepts). An animal's brain—human or otherwise—makes these inferences without awareness of doing so. From this perspective, understanding the neurobiological basis of inference is part of understanding the neurobiology of fear.

JL: A staple of research on fear has, of course, been the fear-conditioning paradigm. It has generated a large amount of useful information about how the brain detects and responds to danger. It can also be used to probe human participants about conscious experiences. But in studies of nonhuman animals, for reasons discussed in detail elsewhere, researchers can only measure behavioral and physiological responses. Because similar responses, including amygdala activation, can be elicited in humans with subliminal stimuli that are not consciously perceived and that do not engender reports of fearful feelings, the experience of fear would not seem to be driving the responses. For this reason, the amygdala circuit might be better thought of as a threat circuit or defense circuit than a fear circuit. Thus, the limits lie not in our paradigms; rather the paradigm exposes the limits of what can be learned from animals versus humans when using these paradigms. Our understanding of fear is, however, limited by other things. One is the fact that truly frightening and traumatizing situations, for ethical reasons, cannot be used in laboratory studies of fear; milder proxies only give us hints, as brain responses do not scale linearly with stimulus intensity. Another is conceptual complacency and loose use of language.

As noted above, popular views of fear and fear conditioning are tethered to Mower and Miller's conceptualization dating back to the 1940s. The term "fear conditioning" implies that the task reveals how fear arises. If one thinks of fear as a conscious experience, as I do, fear conditioning (or what I call "threat conditioning") can in principle be used in animal studies to help understand processes that contribute indirectly to fear; however, it cannot reveal the mechanisms underlying human fearful experiences, which can only be studied in human beings (I do not deny animal consciousness as a natural phenomenon but question whether we can study this scientifically).

I believe that the use of mental-state words like "fear" to characterize behavioral-control systems inevitably creates confusion and leads to misplaced expectations about what animal research can and cannot tell us. Thus, if someone uses the word "fear," then he or she should clarify the intended meaning of "fear" each time the term is used (for example, adding adjectives such as "conscious" or "nonconscious" or "explicit" or "implicit") to avoid confusion. Separating conscious fear from nonconscious threat processing from the start would avoid such confusion.

A staple of research on fear has, of course, been the fear-conditioning paradigm. It has generated a large amount of useful information about how the brain detects and responds to danger.
—Joseph LeDoux

KR: The most common current approaches to study fear in preclinical model systems are based on Pavlovian fear-conditioning models—examining the different memory-related constructs of acquisition, expression, extinction, and so on, of a fear memory—and use behavioral metrics of freezing, avoidance and startle. Similarly, in most human models, laboratories have sought to perform controlled experiments but generally by using self-reports or physiological outcome measures (for example, electrodermal skin response, heart rate or acoustic startle). A limitation to most translational studies is that the human and model-system studies generally do not use the same paradigms and same outcome metrics.

Furthermore, using well-controlled learning paradigms makes it harder to explicitly define pathways and agreed-on circuits related to innate or unconditioned fear cues, processes and behaviors, particularly in animal model systems. Generally, the more controlled and reductionist the experimental paradigm, the harder it is to observe and quantify natural threat response patterns and their underlying biology.

KT: I think having a very stereotyped behavioral paradigm for Pavlovian fear conditioning has facilitated reproducibility and a deeper dive into the anatomy and mechanism (for pairing pure tones to co-terminating foot shock in rodents). There are many other types of fear, however, that have been understudied or not yet studied at all, leaving us with more depth and less breadth in our understanding of fear. At this point, the vast majority of publications on fear refer to a very specific paradigm that is only a tiny subset of the neural mechanisms of this emotional state.

Q6: Can animal models inform us about human models of fear (and vice versa)?

RA: I would say studies in animals are essential to understanding fear, since they allow much better measurements and manipulations than is the case in humans—neither are "models" of anything. The animal studies investigate animal fear; the human studies investigate human fear. No doubt there will be both similarities and differences between any different species, and some animals will have functionally defined fear states that are completely absent in others (animals that don't live in an environment with aerial predators will not have the circuit involving the superior colliculus that processes that type of threat in mice). The reason I actually favor animal studies over human studies is that they can simplify what we are looking for. As I noted earlier, studies in humans typically mix the study of fear with the study of the concept of fear, the conscious experience of fear, or the verbal report of fear. A mouse certainly doesn't have the verbal report and is unlikely to have the concept, and we don't know how to measure its conscious experience—when confronted with a threat, it is just in a functionally specified state of fear. It is also much easier to induce ecologically valid emotions in animals (they don't know they are in an experiment), and it is much more difficult for animals to volitionally regulate their emotions. For all these reasons, studying genuine, intense emotions in animals is far easier than studying them in humans and should be the place where neuroscientists start.

MF: Absolutely, and they have. Wolpe's development of exposure-type therapy was drawn from animal work by Pavlov and Hull and still stands as the signature treatment for anxiety disorders. Mobbs has provided a sophisticated expansion of predatory imminence theory that allows it to capture many of the unique features of human emotion.

LFB: Animal models can inform us about human instances of fear, but currently there are several obstacles. First, most animal studies are performed in just a few model species and fail to consider the similarities and differences in brain-based and niche-based features of different species and as model systems for neurotypical human brain development and function. The computational role of most major brain parts remains conserved across the vertebrate lineage, and all brains can be described as automatically and effortlessly forming inferences (that is, ad hoc concepts) to categorize anticipated sensory inputs and guide action. But species may differ in the type of concepts that a brain can construct, because of general brain-scaling functions and the information available in an animal's niche. For example, the human brain has expanded association cortices compared with other primates, enabling increased information compression and dimensionality reduction; this suggests that human brains may be able to create multimodal summaries characterized by more abstraction.

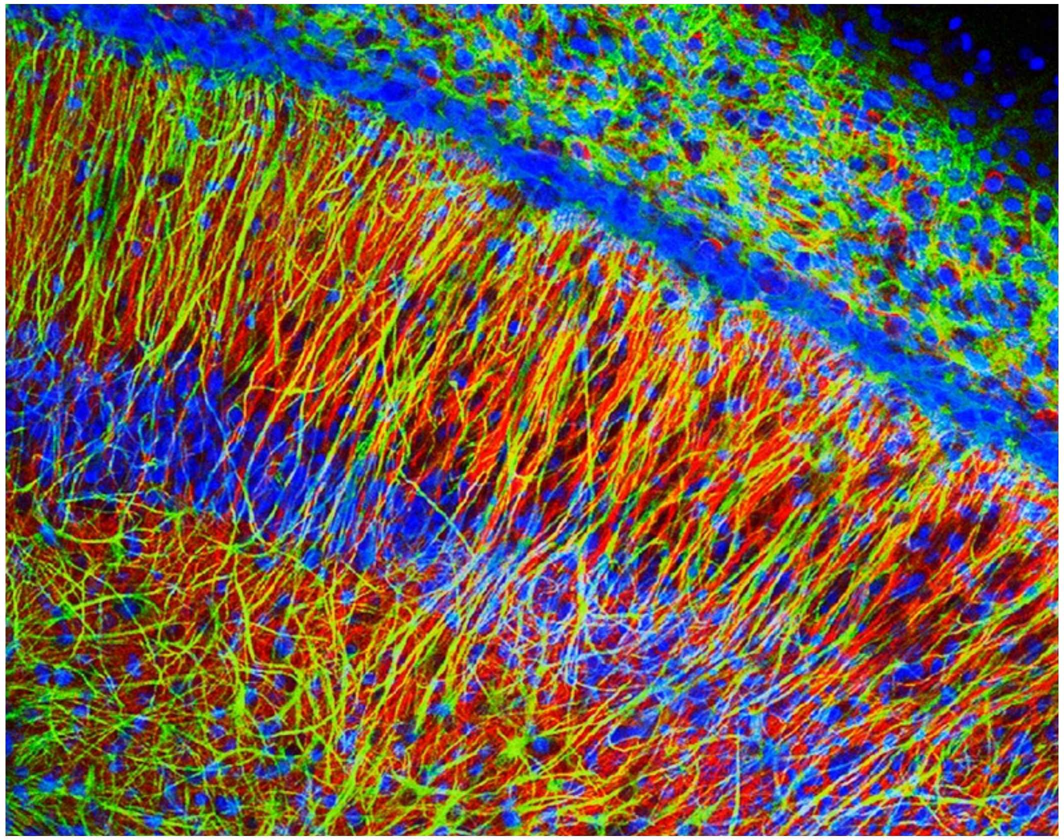
This hypothesis in no way diminishes the importance of survival-related behaviors in human emotion, nor does it invalidate the importance of studying survival-related behaviors in animal models for the purposes of understanding the biology of human emotion. It does suggest, however, that solving the puzzle of human emotion—and human evolution more generally—may require a science of "emotion ecology" that attempts to understand species-general and species-specific processes. Moreover, experimental animals are typically reared in impoverished laboratory settings with fewer opportunities to encounter the range of sensorimotor challenges than are typical in natural ethological contexts; this likely impacts brain wiring during development, prompting the question of whether lab animals are even "neurotypical."

Specifically, I agree with Adolphs's idea that a "functionalist view of emotions like fear requires an interdisciplinary approach."
—Kerry Ressler

JL: The answer to this question is obviously yes, but the details depend on the animal in question and what one means by fear. Invertebrates can potentially inform us about cellular and molecular mechanisms of threat learning in mammals, including humans. Nonprimate mammals can potentially inform us about circuits that detect threats and control various responses (for example, reactions, habits, instrumental actions). Nonhuman primates can potentially inform us about cortical circuits that underlie deliberative cognition. But in each case it is important to verify, to the extent possible, the relevance of the findings to humans by doing studies that approximate the animal studies in humans, albeit with less neurobiological detail. Human research is also necessary to study the conscious experience of fear and other emotions. This is true for at least two reasons. First, methodological barriers limit the assessment of consciousness in nonhuman animals. We can, as Jeffrey Grey put it, only creep up on consciousness, using behavioral proxies in nonhumans. Flawed though it is, verbal report is a powerful tool in humans. We can typically respond verbally or nonverbally to information of which we are conscious but can only respond nonverbally to information for which we lack awareness; with only nonverbal responses, it is difficult to distinguish between conscious and nonconscious processing in other animals. Second, even if we assume that some nonverbal tests reveal aspects of consciousness in nonhuman animals, the nature of consciousness is likely to be quite different given the human brain's unique capacities for language, hierarchical cognition, conceptualization, prospective cognition and self-reflection, which I believe all contribute to fear and other emotional experiences.

KR: While it is clear that few, if any, animal models fully represent the complexity of human neuropsychiatric disorders, there is tremendous evidence for conservation across species—from mouse to human—for basic behaviors, including for many of the defensive threat responses and their underlying circuits. Data robustly suggest that appetitive and aversive behaviors, respectively, are underlying phenomena for the syndromes of addiction and fear-related disorders such as phobia, anxiety and post-traumatic stress disorder (PTSD). Furthermore, the subcortical amygdala, bed nucleus of the stria terminalis (BNST), striatal, hippocampal and brainstem circuits, and to some extent aspects of cortical regulatory areas, are highly conserved in form and function across mammals. Decades of work have established a clear circuitry that has largely held up in human imaging and physiology studies and in rodent studies using modern tools such as optogenetics, chemogenetics, calcium and electrophysiology tools. While much more needs to be established, powerful approaches such as single-cell RNA sequencing across regions and species, large-scale genetic tools combined with transcriptomics, and digital phenotyping across species are enabling truly novel and powerful translational approaches that do not model disorders per se. They instead model their component parts, from molecules to circuits to aspects of behavioral syntax that underlie the defensive threat to fear continuum.

KT: New technologies and methods can enhance our understanding of fear as they can advance our understanding of brain circuitry and function in general. Fear conditioning is often a first proof-of-principle behavioral paradigm used to validate new technologies because it is so robust and reproducible.



CHRIS HENSTRIDGE *GETTY IMAGES*

Q7: How can new technologies and methods enhance our understanding of fear?

RA: Much attention has been paid to increasing the precision of measurements and manipulations of the brain, but I think we need to improve the validity of stimuli and measurements of behavior. Only a few studies have used high-dimensional, multivariate measures of behavior. For instance, one can measure the change in the body surface over tens of thousands of little chromatophores that cuttlefish use to camouflage themselves, a measure that has been claimed to give us a direct readout of the animal's perceptual state. Rich measures in humans would also seem achievable: we need to measure in detail people's movements in 3-D space, their whole-body blood flow and so forth. At the stimulus end, the best stimulus is the real world, and studies in an animal's natural environment or in a person's everyday life would help to provide validity to studies in the lab. Virtual reality could probably help here. Of course, behavior isn't everything (fear doesn't just function to cause behavior); interactions with other cognitive processes are important to quantify as well. In the ideal case we would probe not only how behavior changes over time when an ecologically valid threat stimulus is presented but also how this affects memory, attention, perception and decision-making.

MF: Particularly useful is our ability to map large cellular networks that participate in different situations and behaviors. These have largely been achieved using immediate early gene-imaging techniques such as catFISH. Above, I described Bernstein's research that used this methodology to show that taste aversion and fear conditioning activate largely independent amygdala networks, helping us distinguish two aversive motivational systems. New implantable microscopes also hold considerable promise in advancing our understanding. But our conceptual understanding of phenomena cannot be sacrificed to these technical achievements; the two must advance hand-in-hand.

LFB: New technologies and methods can enhance our understanding of fear by providing the capacity to observe animals in a wider variety of highly variable ethological contexts using higher-dimensional measurement procedures with improved temporal and spatial specificity. The ability to measure and model naturalistic contextual variation is crucial, particularly for genetic studies; most genetic variation related to individual differences that predispose an animal to disease sits in noncoding regions of the genome, which are strongly influenced by context.

JL: The new methods available today are revolutionizing brain research. But sometimes the methods seem to take precedence over the questions. New methods can only help us if we have adequately conceptualized the problems. Complications from poorly designed studies are relatively easily corrected—just do a better experiment. Conceptual problems are harder to change. Ideas become dogma, and dogma typically goes unquestioned; new methods can't fix that. It's good that in this exercise we are taking a step back to assess where we are, conceptually, relative to where we need to be.

KR: An array of fantastic new molecular tools, from optogenetics to chemogenetics to in vivo dynamic imaging, has allowed a functional dissection of cells, molecules and pathways that underscore threat processing and inhibition. Understanding these processes will provide novel and robust insights into control of specific kinds of emotional responses, in particular fear and threat. From a translational perspective, such a cellular level of precision of behavioral control leads to remarkable possibilities. Through single-cell RNA sequencing, we can now assess whether cell types and microcircuits are conserved from mouse to human. Furthermore, we can ask whether these conserved pathways also share molecular targets, so that one could apply data analytics and bioinformatics toward understanding combinations of drugs that might specifically inhibit conserved fear circuits or enhance extinction circuits. For example, even in humans, could we use brain-stimulation techniques or even gene therapy to target fear circuits in reliable, therapeutic ways?

The fundamental issue we are discussing is the role of subjective experience in the science of emotion. Is it one of many aspects of emotion, or is it what emotion is all about?
—Joseph LeDoux

CONCLUDING REMARKS
After this discussion, can we agree on a definition of fear?

RA: I think we want to be careful to leave room open for revision and discovery, rather than rigidly defining fear. Perhaps we could agree on these points: (i) fear involves particular regions of the brain, especially clearly subcortical ones. We can measure it from, and induce it by manipulating, particular neural circuits (for example, the amygdala) and not others (for example, the cerebellum). Whether these circuits are specific to fear is a further empirical matter. We could come up with some initial inventory of how strong the evidence is for the participation of particular brain structures in fear. (ii) There are subtypes, varieties or dimensions of fear. I would advocate, in the first instance, for differentiating it based on functional criteria. We could come up with lists here, too. (iii) The state of fear, the conscious experience of fear, the concept of what "fear" means and the meaning of the word "fear" are all different things (the latter two can only be studied in humans). If you give people words or stories to rate, you are testing the last two. It would be useful to come up with taxonomy or a glossary for this.

MF: Several of the approaches (Aldolphs, Ressler, Tye and Fanselow) seem to take evolutionary concerns and commonalities between fear expression as central. Importantly, these approaches recognize that something can be learned from all measures of fear. LeDoux and Feldman Barrett stand apart. In my opinion, their approaches suffer from the human tendency to glorify verbal report over all other measures. So, the hurdle is to agree to treat verbal report as informative, but not exclusively so. LeDoux's description of the circuitry supporting conscious reporting of fear recognizes that there is significant input from the amygdala and other components of the antipredator system. I believe this is also true of Feldman Barrett's description, although she does not discuss explicit circuitry. The circuitry that gives rise to any individual fear response will have two components. One component arises from the core defensive circuit, and this will be similar for all fear responses. But there will also be a second component providing specific information, and the processing necessary, for execution of the particular response.

This is just as true of freezing as verbal report. Each response will have its own unique subcircuit, part of which will belong to an essential circuitry common to all fear responses. Each response reflects both fear and other contextual information. If we recognize this, then we may be close to consensus. Even something seemingly simple as freezing is a complex construction. The firing of basolateral amygdala neurons that initiates freezing is brief and transient and needs to be converted elsewhere into the firing patterns necessary to maintain a sustained motor response. The motor pattern we call freezing varies considerably in posture; the freezing rat can be crouching on the ground or rearing up and leaning on a wall. This is remarkably similar to Feldman Barrett's description of "many to one" response mapping where the intention to freeze is implemented by different motor plans. Freezing does not occur in random places: animals preferentially freeze near walls, in corners and in dark locations. Thus, the freezing subcircuit processes visual contextual information that is quite separate from the sensory stimuli that signal danger. Past experiences will also influence current action. These multiple streams of information must coalesce in a manner that supports each instance of freezing. Thus, even freezing is, in Feldman Barrett's words, "highly context-dependent and variable." Maybe we are not so far apart after all.

LFB: I am optimistic and hopeful that scientists can reach agreement on defining fear, but it will require that we reconsider some of our ontological commitments and the philosophical assumptions that ground our empirical inquiry. Several of the debates within the science of fear (and the science of emotion, more generally) are philosophical rather than scientific and so are unlikely to be resolved with experiments or data. Still, discussions like these are worth having, because commitments and assumptions are conceptual tools that influence (and constrain) the process and products of scientific inquiry.

JL: The fundamental issue we are discussing is the role of subjective experience in the science of emotion. Is it one of many aspects of emotion, or is it what emotion is all about? This is a perennial issue in emotion theory. The reason we are discussing this as if it was a novel topic here is because much contemporary research on the brain mechanisms of fear has involved fear conditioning, which has largely been isolated from mainstream emotion theory. My Ph.D. dissertation in the late 1970s included studies of emotional consciousness in split-brain patients and introduced me to the cognitive theory of emotion. Ever since, I have viewed emotions as cognitively assembled states and tried to integrate cognitive thinking about emotion into the fear conditioning (or what I call "threat conditioning") field. But it has been an uphill battle. For example, sometime in the late 1980s, one of my colleagues from the behaviorist tradition asked me, "why do you talk about fear conditioning in terms of emotion?" These days, for better or worse, emotion talk is fairly common in the animal aversive conditioning field. But the conception of emotion is often still heavily influenced by the Miller–Mowrer behaviorist "fear theory" from the 1940s, which treated conditioned fear as the underlying factor in avoidance. While some from the behaviorist tradition, especially in the tradition of Tolman, viewed fear in animals as an intervening varaiable, a hypothetical central state (for example, a hypothetical nonsubjective psychologicial or physiological state) that might connect stimuli with behavior, others viewed it as a subjective conscious experience; however, most did not take a stand either way, which has engendered much confusion. Research on the brain mechanisms of fear in humans has also often used the term "fear" in ways that conflate behavioral and physiological responses with subjective experiences, further adding to the confusing state of affairs in which now find ourselves.

I would say studies in animals are essential to understanding fear because they allow much better measurements and manipulations than is the case in humans—neither are "models" of anything.
—Ralph Adolphs

As I noted above, some of the disagreements among the participants in this discussion are mostly semantic. But, also as noted, semantics are crucial to our conceptions and assumptions. It's a good thing that different ideas are being expressed. Fear has too long been talked about in ways that imply we all mean the same thing. Now that different conceptions are being openly discussed, it would, as I suggested above, be useful for researchers to be more rigorous and vigilant in defining what each means by "fear" each and every time the term is used, so that others will understand what is being referred to in a given instance. The less cumbersome alternative, which I prefer, is simply to confine fear to fear itself. As the social psychologist Matthew Lieberman recently argued, "emotion is emotional experience." More generally, mental state terms like fear should be used to refer to mental states and not to behavioral or physiological control circuits.

KR: I believe that we can agree on a definition. I think most everyone already states some of the shared understanding of a subset of the conscious awareness components in humans, as well as observable physiological and behavioral components in humans and model systems. I think that separating the salience, valence and action (or perhaps feeling, perception and behavior) descriptions will help with some of the semantics. Additionally, I think that focusing on pragmatism over theoretical will help with efficiency toward a workable definition.

In your view, what are the clinical implications of a clear definition of fear?

RA: The clinical implications are huge. Probably the best evidence for this is the paper by LeDoux and Pine and subsequent rebuttals by Fanselow. LeDoux and Pine argue that the effects of anxiolytic drugs studied in rodents do not inform about the conscious experience of fear and that this is why anxiolytic drugs don't work well for alleviating fear in humans: they are aiming at the wrong target. For instance, an antidepressant that makes depressed people really awake and active and gets them out of bed in the morning would not be helpful if they still feel depressed. This is just one example, but it shows how important it is to figure out what we are studying when we study fear in animals and in humans and when we measure or manipulate its neural components.

MF: The scientific definition of fear must help us understand the clinical manifestations of fear. Let's start with what I see as the two big questions. First, why are anxiety disorders so prevalent? Elsewhere I've described this as a natural and predicted consequence of the costs and benefits of hits versus misses when assessing the presence of threat. Second, why are anxiety disorders so detrimental? Fear, anxiety and panic in the absence of actual danger are not beneficial, so why doesn't the realization of this fact make anxiety disorders disappear? I believe this is a consequence of engaging a system whose strategies are determined by contingencies that operated over phylogeny rather than ontogeny. I also come back to my point that if consciousness evolved to allow flexible and rational decision-making, the lack of flexibility and rational action that characterizes anxiety disorders suggests that conscious contributions are limited. I'm not saying that there is no contribution, but we must temper our conclusions with the facts of the clinical situation.

LFB: One goal of understanding the neurobiological basis of fear is to aid the treatment and prevention of mood-related symptoms in both mental and physical disorders. This goal will be accomplished only when we consider the mechanisms and features of fear in the context of what the broader range of evidence actually suggests about the evolution and development of the nervous system. An evo-devo approach requires considering what the broader range of evidence actually suggests about features of the human nervous system that are deeply evolutionarily conserved versus features that emerge during human vs nonhuman brain development. In addition, scientists should understand that disorders which strongly implicate fear and/or anxiety, such as PTSD, are not specific fear disorders; this has implications for how these disorders are understood, treated and prevented.

JL: In the face of a sudden danger, we typically consciously experience fear and also respond behaviorally and physiologically. Because the experience and the responses often occur simultaneously, we have the sense that they are entwined in the brain and thus are all consequences of a fear module. This is a common and popular view of fear, and it has led us to search for medications and behavioral treatments that will relieve subjective distress in patients suffering from fear or anxiety disorders. Since the behavioral and subjective responses are both assumed to be products of a fear module, it is also assumed that treatments that alter behavior in animals will alter fear and anxiety in people. Few would claim that this effort has been a rousing success. Small but statistically significant differences relative to placebo controls are found in some studies, but for any one individual the chances of successful treatment are much lower than desirable. And even when successful, side effects pose other problems.

But more pertinent to our concern here is why these treatments help, when they do. Is it because the treatment directly changes the content of the subjective experience, or because it indirectly affects the experience (for example, by reducing brain arousal, feedback from body responses), or because it affects cognitive processes that contribute to the experience (episodic and semantic memory; hierarchical deliberation, working memory, self-awareness), or all of the above? For the patient it probably doesn't matter how a treatment works, but for the purpose of finding new and better medications, knowing the underlying mechanism of action is crucial. And to understand this we need a conceptualization of not just how the brain controls behavioral and physiological responses elicited by threats but also how the threat engenders the conscious experience of fear—something that can only be explored in humans. After many decades of being marginalized as just another measure of fear, there is renewed interest in consciousness (including emotional consciousness) in psychology, neuroscience and the various psychotherapeutic communities—not simply because subjective experience is an interesting research topic but also because it plays a central role in our lives and must be a central part of therapy.

KR: Disorders of fear processing (and related panic and anxiety), from panic disorder, social anxiety and phobia to PTSD, are among the most common of psychiatric maladies, affecting hundreds of millions of people worldwide. Combined, they are also among the highest in terms of morbidity, loss of work, comorbid psychiatric and medical disorders, and mortality from suicide. Despite these unfortunate statistics, we understand these disorders moderately well and have reasonable treatments. These disorders all share the core emotion of fear and threat-related symptoms. The diagnosis of a panic attack, shared among all of these disorders, includes racing heartbeat, sweats, chest pains, breathing difficulties, feelings of loss of control and a sense of terror, fear, impending doom and death—basically the fear reflex run amok! The reflexes and symptoms that are "normal" in a threatening situation are experienced by those with anxiety disorders all the time—as if they can't "turn off" the fear switch. Furthermore, the most well-supported, empirically validated treatments for these disorders rely on repeated exposure, now understood as the process of fear extinction. Advances in our understanding of mechanisms of fear and threat processing, its underlying neural circuitry and molecular biology, and improved methods of fear inhibition and extinction will contribute to advancing treatment and prevention for these devastating disorders.

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—Kerry Ressler

What is an important gap that future research (and funding) should try to fill?

RA: Integrative, cross-species research. Right now research on fear (and other emotions) is like the blind men and the elephant. Each lab studies either humans or a single animal model, and each study focuses on a narrow aspect of fear. We need to figure out how to put all this together. I'm not suggesting a giant project where all manner of species and humans are studied, but we should produce standardized sets of experimental protocols that the scientific community can use—in particular, these protocols and their measures have to cut across species to some extent. Currently research on fear in animals and in humans is really disconnected, and that has to change if we are to make progress. We need uniform criteria for evaluating papers and grants and for building a cumulative science of fear. Needless to say, the by-now-common criteria of reproducibility and data sharing should apply also.

My view is that the biggest impediments to progress are our conceptions and the language we use to characterize psychological constructs.
—Joseph LeDoux

MF: Current technical developments in neuroscience are both important and breathtaking, but where we fall short is conceptual development and advancing formal theories of behavior. Without conceptual development, the data being collected with those tools can be, and often is, profoundly misinterpreted. While some of the contributors to this discussion bemoan the influence of behaviorism, I feel that a far more problematic trend is the intuitive, and often anthropomorphic, approach to behavior that characterizes much of the most technically advanced neuroscience going on now. This caution was a major motivator for the initial development of behaviorism. Again, I note that the negative comments regarding behaviorism above were directed at an outdated form of behaviorism that learning theorists discarded decades ago, and these comments can therefore be considered strawman arguments. Behavior is of paramount importance, not only because it allows objective observation, but also because it is where the organism connects with selection pressure. Careful observation of emotionally charged animals shows that behavior is often irrational and our intuitions about how to interpret it are likely to fail. I call "predatory imminence theory" a functional behavioristic approach because its ideas flow from concerns about both evolution and behavioral topography.

LFB: Every behavior is the result of an economic decision about an animal's global energy budget and involves estimating expenditures and deposits over various temporal windows that are relevant to the niche of the animal, taking into account the animal's current physiological condition. If fear is to be understood in an evolutionary and developmental context, then it must be studied in the reality of those economic decisions as they emerge in an animal's ethological context. More attention must be paid to basic metabolism and energy regulation, including the cellular respiration of neurons and glial cells. A predictive processing approach, rather than a stimulus–response approach, must also be considered. And a greater emphasis on variation and degeneracy, at all levels of analysis, as well as neural reuse, must be considered.

JL: My view is that the biggest impediments to progress are our conceptions and the language we use to characterize psychological constructs. My personal preference is that mental-state terms, such as fear, should be avoided when discussing relatively primitive processes that control behavior; mental state words should only be used when specifically referring to mental states, such as the conscious experience of fear.

KR: I agree with Tye that "given its critical importance in survival and its authoritarian command over the rest of the brain, fear should be one of the most extensively studied topics in neuroscience, though it trails behind investigation of sensory and motor processes due to its subjective nature." I feel that it is among the lowest hanging fruit in behavioral and translational neuroscience, and that an explanatory science—from molecules to cells to circuits to behavior—will provide a transformative example for other areas of neuroscience and neuropsychiatry. I think current gaps include many of the questions raised in this discussion, such as how are valence, salience, perception and action separated at a neural circuit level. Are there critical differences between predatory vs. social survival circuits and between reactive vs. cognitive fears? How discrete, at a cellular circuit and microcircuit level, are the different components and behaviors underlying threat processing? Finally, from a translational perspective, how are the molecules, cells and circuits conserved in humans—which ones constitute convergent evolution of similar behaviors with distinct mechanisms vs. which represent truly conserved mechanisms that are essentially the same in rodents and humans?

KT: The field would benefit greatly from additional paradigms that are distinct yet stereotyped to facilitate the same critical mass of research surrounding it that Pavlovian fear conditioning has undergone to really be able to make comparisons.

SUMMARY

Substantial progress has been made in our understanding of the neural circuits involved in fear. This has been a cross-species endeavor, yet—as debated here—there are disparities on how to investigate and define fear. We hope that the debate presented here, which represents the views of a subset of outstanding researchers in the field, will invigorate the community to unify on clear definitions of fear (and its subtypes) and to show the courage to pursue new behavioral assays that can better differentiate among fear circuits (or concepts) involved in perception, feeling and action. The implications will be far-reaching, as a lack of coherence on what neural systems are involved in fear and fear learning will hinder scientific progress, including the study of human affective disorders such as PTSD, anxiety and panic disorder. That is, how we define fear determines how we investigate this emotion.

The Scientific Underpinnings and Impacts of Shame

People who feel shame readily are at risk for depression and anxiety disorders

By Annette Kämerer

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Annette Kämmerer is a psychologist and professor emerita at the Institute of Psychology at Heidelberg University in Germany. She sees patients in private practice and trains young psychotherapists.

We have all felt shame at one time or another. Maybe we were teased for mispronouncing a common word or for how we looked in a bathing suit, or perhaps a loved one witnessed us telling a lie. Shame is the uncomfortable sensation we feel in the pit of our stomach when it seems we have no safe haven from the judging gaze of others. We feel small and bad about ourselves and wish we could vanish. Although shame is a universal emotion, how it affects mental health and behavior is not self-evident. Researchers have made good progress in addressing that question.

BAD FOR YOUR HEALTH

According to philosopher Hilge Landweer of the Free University of Berlin, certain conditions must come together for someone to feel shame. Notably, the person must be aware of having transgressed a norm. He or she must also view the norm as desirable and binding because only then can the transgression make one feel truly uncomfortable. It is not even always necessary for a disapproving person to be present; we need only imagine another's judgment. Often someone will conjure an image of a parent asking, "Aren't you ashamed?" Indeed, we may internalize such admonishments so completely that the norms and expectations laid on us by our parents in childhood continue to affect us well into adulthood.

June Tangney of George Mason University has studied shame for decades. In numerous collaborations with Ronda L. Dearing of the University of Houston and others, she has found that people who have a propensity for feeling shame—a trait termed shame-proneness—often have low self-esteem (which means, conversely, that a certain degree of self-esteem may protect us from excessive feelings of shame). Tangney and Dearing are among the investigators who have found that shame-proneness can also increase one's risk for other psychological problems. The link with depression is particularly strong; for instance, one large-scale meta-analysis in which researchers examined 108 studies involving more than 22,000 subjects showed a clear connection.

In a 2009 study, Sera De Rubeis, then at the University of Toronto, and Tom Hollenstein of Queen's University in Ontario looked specifically at the trait's effects on depressive symptoms in adolescents. The project included roughly 140 volunteers between the ages of 11 and 16 and found that teenagers who exhibited greater shame-proneness were also more likely to have symptoms of depression. There also seems to be a connection between shame-proneness and anxiety disorders, such as social anxiety disorder and generalized anxiety disorder, as Thomas A. Fergus, now at Baylor University, and his colleagues reported in 2010.

SEX AND AGE DIFFERENCES

In 2010 a team of psychologists led by Ulrich Orth of the University of Bern studied shame in more than 2,600 volunteers between the ages of 13 and 89, most of whom lived in the U.S. They found not only that men and women manifest shame differently but also that age seems to affect how readily people experience it: adolescents are most prone to this sensation; the propensity for shame decreases in middle age until about the age of 50; and later in life people again become more easily embarrassed. The authors see this pattern as a function of personality development. The identities of teenagers and young adults are not completely formed; in addition, people in this age group are expected to conform to all manner of norms that define their place in society. Uncertainty as to how to deal with these external expectations may make them quicker to feel shame. By middle age, in contrast, our character is more or less set, and norms have less impact. But as we enter old age and worry about declines in our body and our appearance, we begin to feel self-conscious again.

When we are ashamed, we often find it difficult to look into another person's eyes.

GETTY IMAGES

GUILT AND SHAME: RELATED BUT DIFFERENT

It has been speculated that humans feel shame because it conferred some kind of evolutionary advantage on our early ancestors. For instance, it can potentially promote a group's well-being by encouraging individuals to adhere to social conventions and to work to stay in others' good graces.

Yet Tangney and others argue that shame reduces one's tendency to behave in socially constructive ways; rather it is shame's cousin, guilt, that promotes socially adaptive behavior. People often speak of shame and guilt as if they were the same, but they are not. Like shame, guilt occurs when we transgress moral, ethical or religious norms and criticize ourselves for it. The difference is that when we feel shame, we view ourselves in a negative light ("*I* did something terrible!"), whereas when we feel guilt, we view a particular action negatively ("I *did* something terrible!"). We feel guilty because our actions affected someone else, and we feel responsible.

Tangney and her co-authors explained it well in a 2005 paper: "A shame-prone individual who is reprimanded for being late to work after a night of heavy drinking might be likely to think, 'I'm such a loser; I just can't get it together,' whereas a guilt-prone individual would more likely think, 'I feel badly for showing up late. I inconvenienced my co-workers.' Feelings of shame can be painful and debilitating, affecting one's core sense of self, and may invoke a self-defeating cycle of negative affect.... In comparison, feelings of guilt, though painful, are less disabling than shame and are likely to motivate the individual in a positive direction toward reparation or change."

Further, guilt is a sign that a person can be empathetic, a trait that is important for one's ability to take someone else's perspective, to behave altruistically and to have close, caring relationships. Indeed, we can feel a sense of guilt only if we can put ourselves in another's shoes and recognize that our action caused pain or was injurious to the other person. As is generally true of young children, people who are unable to empathize cannot feel guilt. Guilt holds us back from harming others and encourages us to form relationships for the common good. When we feel guilty, we turn our gaze outward and seek strategies to reverse the harm we have done. When we feel ashamed, we turn our attention inward, focusing mainly on the emotions roiling within us and attending less to what is going on around us.

One study that clearly associates guilt and empathy

As is generally true of young children, people who are unable to empathize cannot feel guilt.

was published in 2015. Matt Treeby, then at La Trobe University in Melbourne, and his colleagues first examined the extent to which test subjects tended toward shame or guilt. Then they had the 363 participants look at facial expressions and determine whether the person was angry, sad, happy, fearful, disgusted or ashamed. Guilt-prone volunteers proved to be more accurate in their observations: they were better able to recognize the emotions of others than were shame-prone volunteers.

Of course, guilt and shame often occur together to some extent. Guilt can trigger a sense of shame in many people because of the discrepancy between the standard to which they hold themselves and the action that caused the guilt. The connection between guilt and shame grows stronger with an increase in the intentionality of our misbehavior, the number of people who witnessed it and the importance of those individuals to us. Shame will also increase if the person who was harmed by our action rejects or rebukes us.

HAUNTED BY ORIGINAL SIN

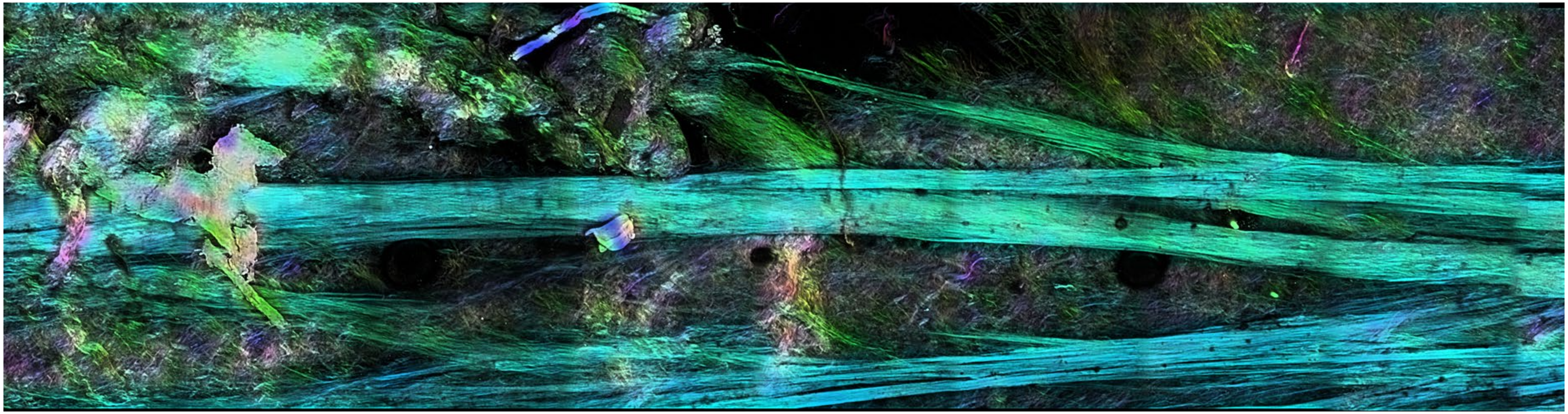
In the Bible, nakedness is a source of shame. The book of Genesis 2:25 says of Adam and Eve, "And they were both naked, the man and his wife, and were not ashamed." That changed when they rebelled against God's commandment and ate of the tree of knowledge. From then on, they felt ashamed in each other's presence: "And the eyes of them both were opened, and they knew that they were naked; and they sewed fig leaves together, and made themselves aprons."

This Biblical interpretation of nakedness as shameful still deeply informs the social norms and conventions that determine how we deal with human physicality and sexuality. Although our notions of whether, how, where and in the presence of whom a person may be undressed have changed over the centuries, the shame we feel when we transgress the norms has remained.

Ridding oneself of guilt is often easier than overcoming shame, in part because our society offers many ways to expiate guilt-inducing offenses, including apologizing, paying fines and serving jail time. Certain religious rituals, such as confession, may also help us deal with guilt. But shame has real staying power: it is much easier to apologize for a transgression than it is to accept oneself.

Some kinds of guilt can be as destructive as shame-proneness is—namely, "free-floating" guilt (not tied to a specific event) and guilt about events that one has no control over. In general, though, it appears that shame is often the more destructive emotion. It follows, then, that parents, teachers, judges and others who want to encourage constructive behavior in their charges would do well to avoid shaming rule breakers, choosing instead to help them to understand the effects of their actions on others and to take steps to make up for their transgressions.

THE ART OF NEUROSCIENCE



"Art or Fact," by Markos Kapeliotis and Rebeca Alejandra Gavrila Laic.

The Brain in Images: Top Entries in the Art of Neuroscience

Scientific American **presents the winner and runners-up of the ninth annual Art of Neuroscience contest, along with other notable entries**

ART AND NEUROSCIENCE have been intertwined for centuries. Early surgeons and scientists who poked and prodded inside cranial cavities—such as Santiago Ramón y Cajal—often drew what they saw. These artistic renderings played a critical role in helping researchers grapple with the mysteries of our most vital organ. (Cajal even shared the Nobel Prize in Physiology or Medicine in 1906 for his drawings.) Methods for exploring the brain have (thankfully) changed, and our understanding has evolved. The desire to visualize what we discover, however, has persisted.

For the ninth year in a row, the Netherlands Institute for Neuroscience in Amsterdam has published the winners of its annual Art of Neuroscience competition. The contest celebrates artists and scientists who strive to illustrate the brain's complexities. This year's entrants questioned the origins of imagination, imaged collagen fiber, modeled starlike brain cells called astrocytes and explored other intricacies. Presented below—selected from 87 submissions representing 25 countries—are the winning entry, four honorable mentions and five works selected by *Scientific American*'s editors.*

*Photography editor Liz Tormes served on the panel of judges for the competition.

MARKOS KAPELIOTIS AND REBECA ALEJANDRA GAVRILA LAIC

THE ART OF NEUROSCIENCE

Winner

AF:CFFiIV *(video still)*

By pt9 (Olesya Ilyenok, Marina Muzyka and Andrey Chugunov)

This video employs three artificial-intelligence-based computing systems inspired by human brain networks. The resulting three neural networks simulate the brain's ability to generate abstract images, sounds and concepts inspired by prior experiences, a phenomenon better known as imagination. In the winning video, produced by members of the pt9 art group at Far Eastern Federal University in Russia, one neural network produces a string of jarring images prompted by a catalog of existing photographs; a second neural network generates image descriptions; and the third neural network reads the descriptions aloud.

PT9: OLESYA ILYENOK, MARINA MUYZAK AND ANDREW CHUGUNOV; IMAGES WERE GENERATED WITH STYLEGAN; VOICE WAS GENERATED WITH GOOGLE WAVENET; IMAGE DESCRIPTIONS WERE GENERATED WITH BETAFACE API

THE ART OF NEUROSCIENCE

Honorable Mention

Ultimate Emoji *(video still)*

by Albert Barqué-Duran

This piece reflects the complex ways we use characters to communicate human emotion. Lecturer Barqué-Duran of the University of Lleida in Spain and City, University London, first analyzed data from a previous project that scraped social media posts to map how people feel about the places they visit. From these data, he identified a series of emotions associated with the Design Museum of Barcelona, and assigned corresponding emoji to those emotions. He then 3-D printed a composite of the emoji. During a live performance at the museum he painted the resulting sculpture.

ALBERT BARQUÉ-DURAN

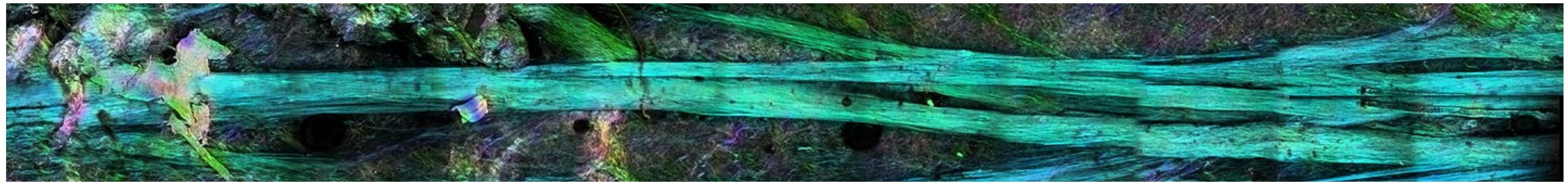
THE ART OF NEUROSCIENCE

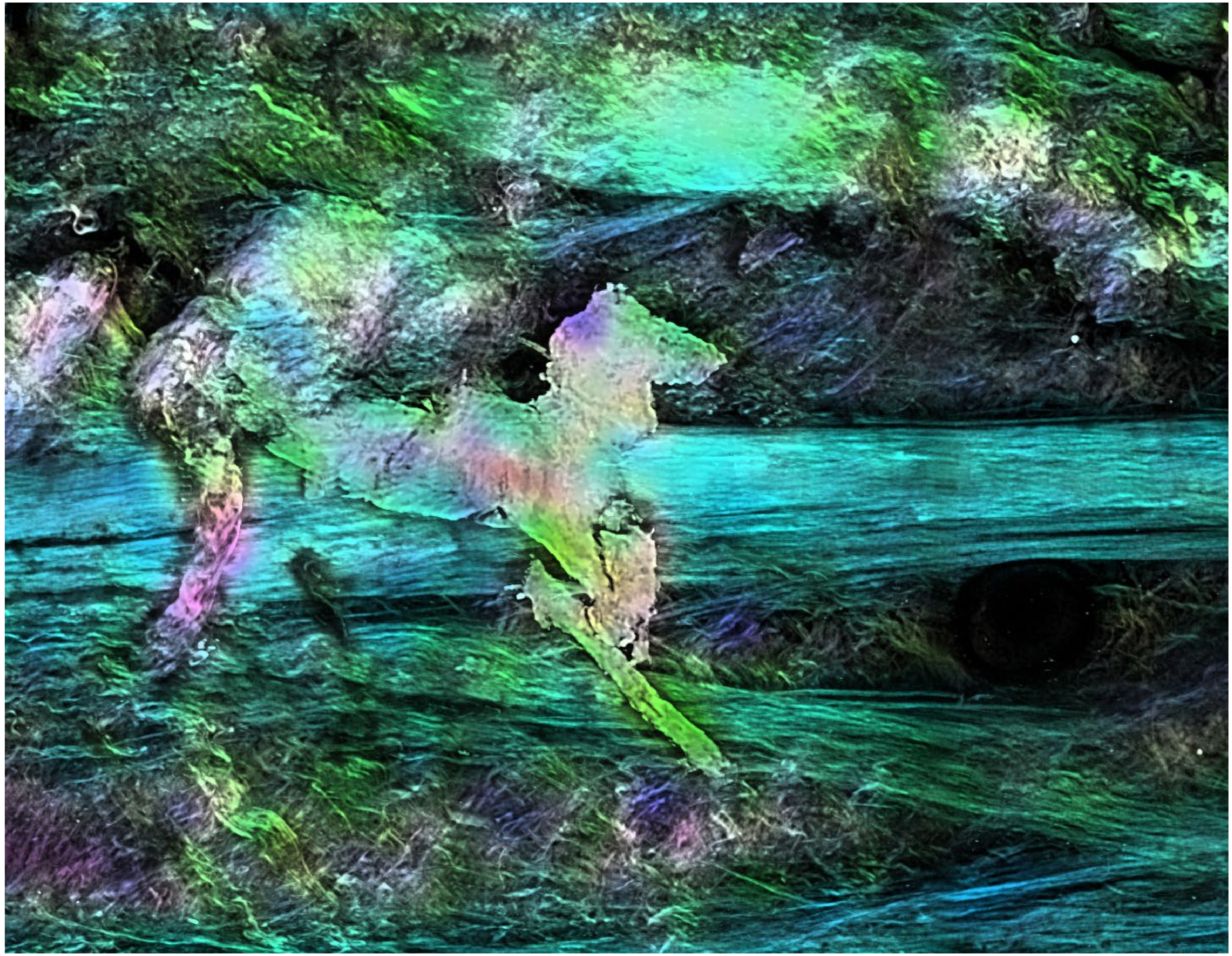
Honorable Mention

"Art or Fact"

By Markos Kapeliotis, Rebeca Alejandra Gavrila Laic, Nele Famaey and Pieter Vanden Berghe

A flood of colorful collagen fibers splay out in this image of a bridging vein (which drains neural tissue), taken by a team at Katholieke Universiteit Leuven in Belgium. Within the brain's tangle of structures and shapes, Kapeliotis and his colleagues were struck, in particular, by the horse-shaped fiber on the left side of the image.





MARKOS KAPELIOTIS AND REBECA ALEJANDRA GAVRILA LAIC

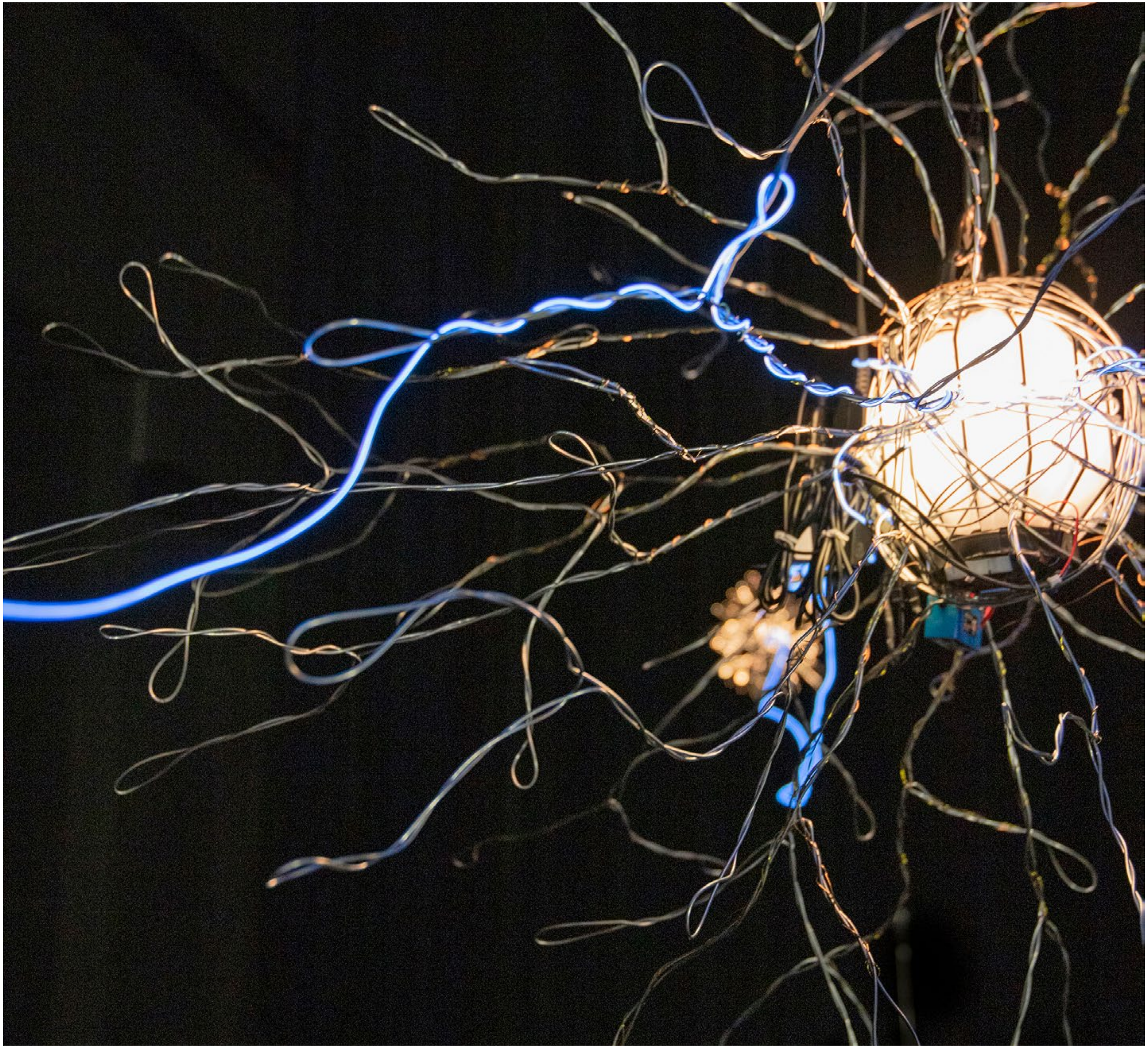
THE ART OF NEUROSCIENCE

Honorable Mention

Starlight Gone *(video still)*

By Elizabeth Parent and Liam O'Leary

Astrocytes, starlike brain cells that support nearby damaged cells, have recently been linked to the onset of depression. In this interactive installation by multimedia artist Parent and neuroscience Ph.D. candidate O'Leary of McGill University, wire astrocyte replicas light up as participants move toward them and dim as participants step away, mirroring the cyclical relation between depression and loneliness.



ELIZABETH PARENT AND LIAM O'LEARY (CRISTIAN ZAELZER-PEREZ, VIDEOGRAPHER)

THE ART OF NEUROSCIENCE

Honorable Mention

Perineuronal Nets in Spring

By Ana Jakovljevi

Biologist Jakovljevi of the University of Belgrade in Serbia crafted a wire replica of a perineuronal net—a web of tissue that wraps around neurons developing in the central nervous system. These structures may be key to understanding neural plasticity in the human brain. The flowers, Jakovljevi said in a statement, represent “the beauty of a neuronal architecture.”

ANA JAKOVLJEVI *UNIVERSITY OF BELGRADE*

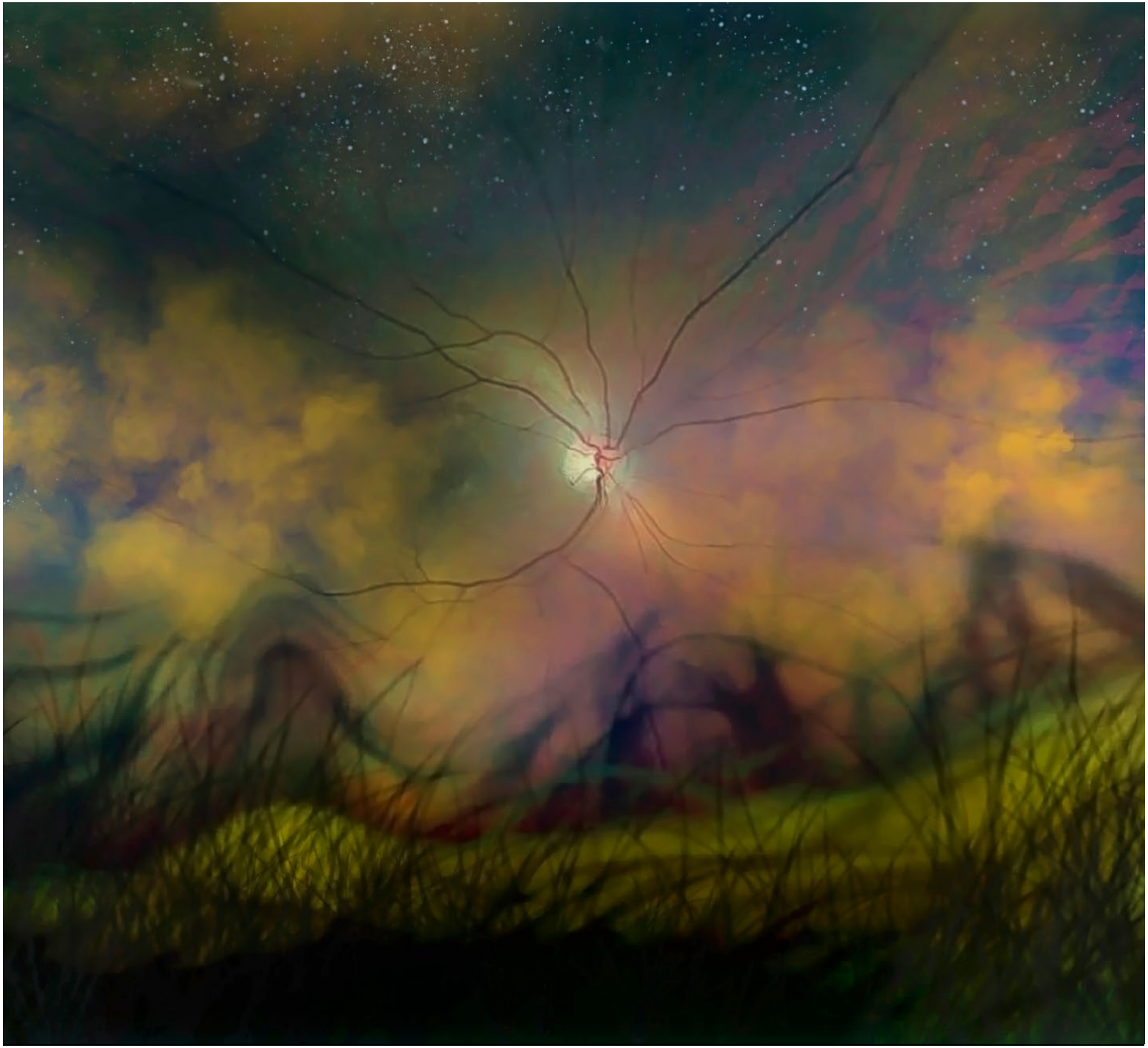
THE ART OF NEUROSCIENCE

Editor's Pick

Looking Inward and Outward

By Rik Gern

"The eyes may be the window to the soul, but the retina is a window to the brain," according to a description of this image from artist Gern, who superimposed a whimsical landscape and star-studded sky onto a retinal scan provided by his optometrist. Light-sensitive cells within the retinal layer trigger the optic nerve, which forms the visual images we see.



RIK GERN

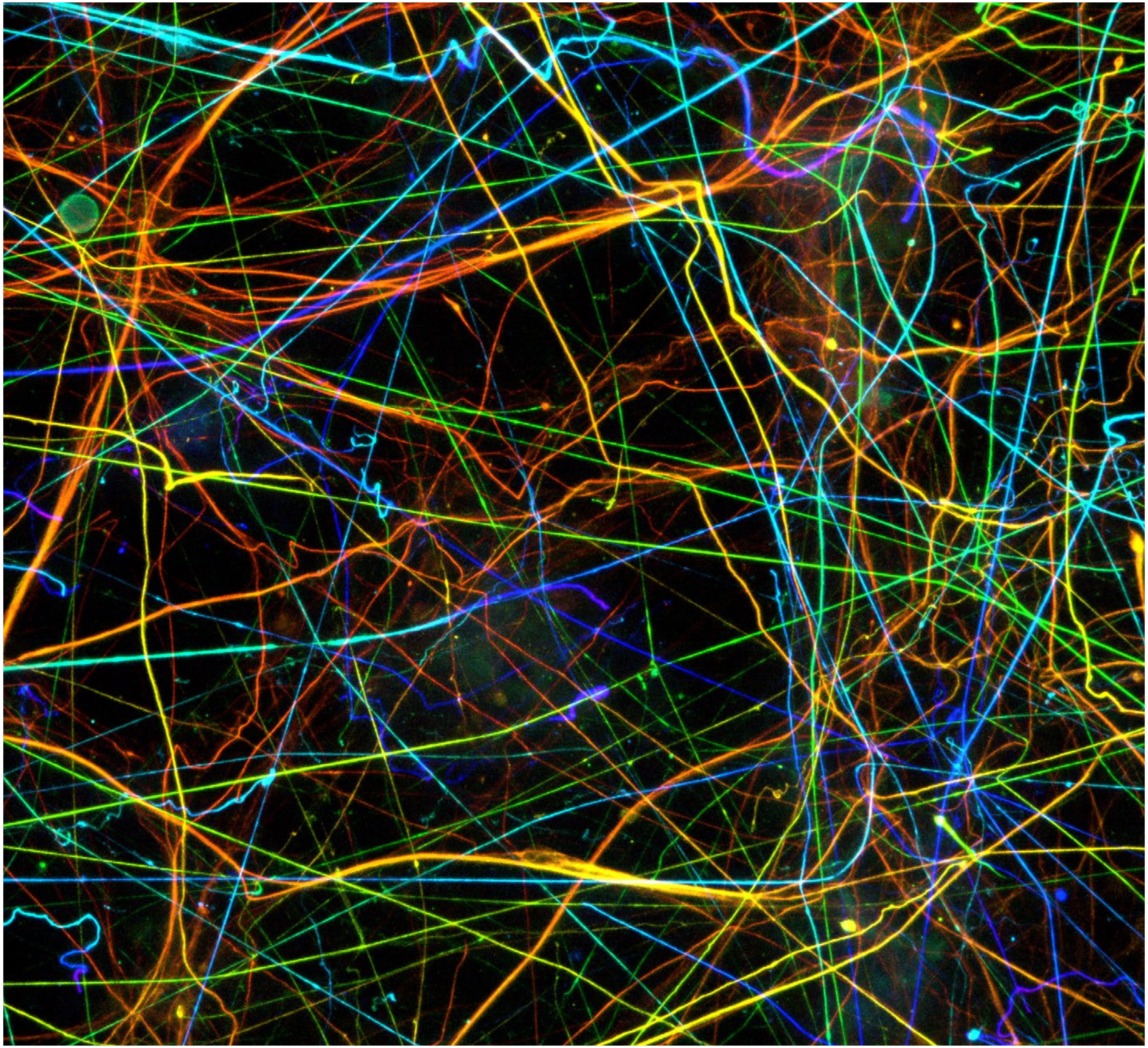
THE ART OF NEUROSCIENCE

Editor's Pick

"Human Neurons Growing in Three Dimensions"

By Kevin Batenburg

This three-dimensional snapshot captures a tapestry of colorful, sinewy neural axons, and was taken by functional genomics researcher Batenburg of Vrije University Amsterdam. Studying the cells in three dimensions allows scientists to get a fuller understanding of the role that neurons play in diseases such as Alzheimer's.



KEVIN BATENBURG *CENTER FOR NEUROGENOMICS AND COGNITIVE RESEARCH, VRIJE UNIVERSITY AMSTERDAM*

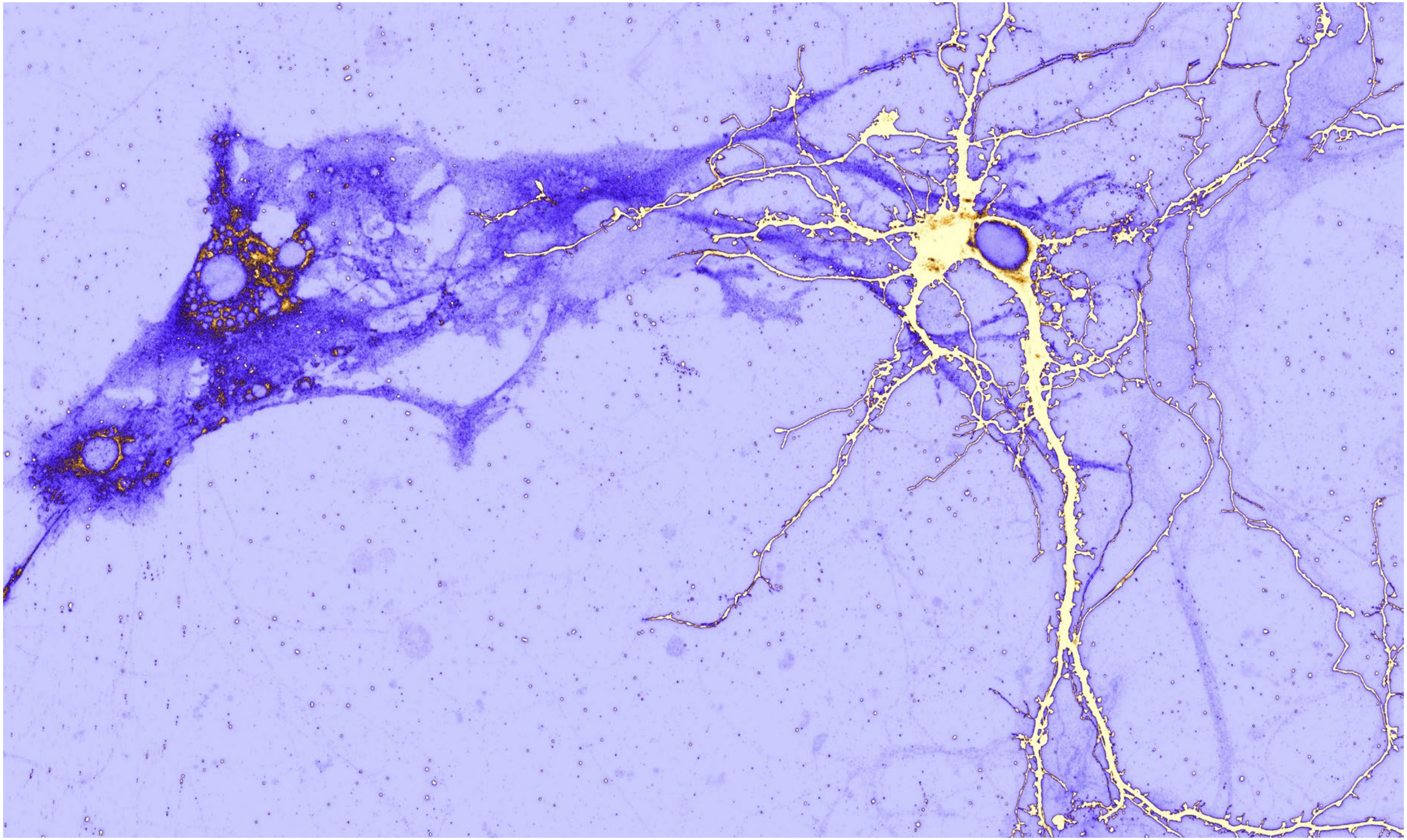
THE ART OF NEUROSCIENCE

Editor's Pick

"I'm Just a Glia, Standing in Front of a Neuron, Asking Him to Love Her"

By Claudio Polisseni

What would neurons be without the glial cells that surround and support them? Nothing, argues physicist Polisseni of the Max Planck Institute for Brain Research in Frankfurt, Germany, who took this image of a glial cell (*purple, left*) wrapping around a neuron (*yellow, right*).



CLAUDIO POLISSENI *MAX PLANCK INSTITUTE FOR BRAIN RESEARCH*

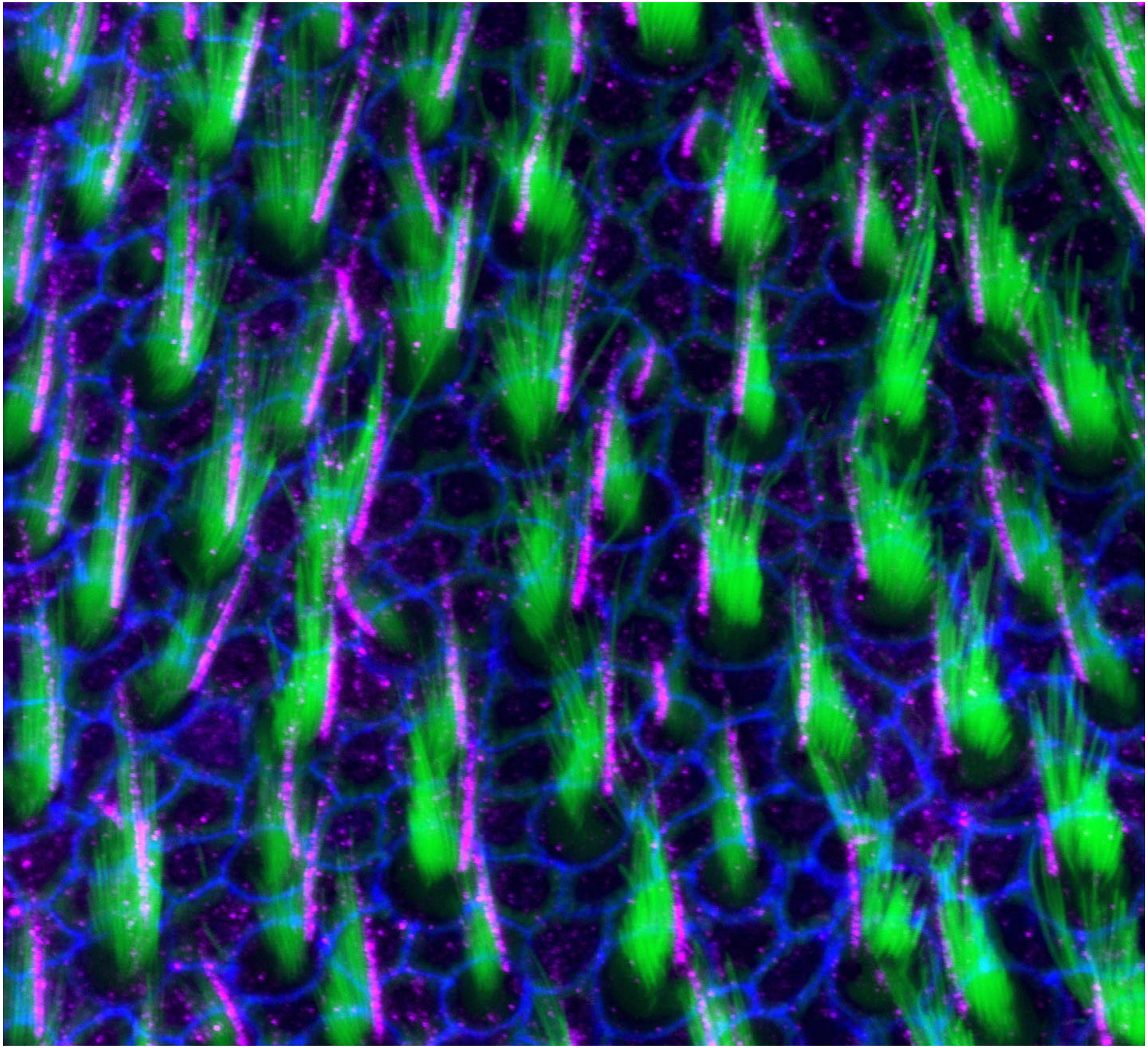
THE ART OF NEUROSCIENCE

Editor's Pick

"Face-Off"

By Dan Jagger

This image shows a mosaic of cells within the utricular macula—the thin membrane within the ear that helps to maintain balance. The hair cells' sensitive bundles of stereocilia (*stained green*) cue the brain to changes in fluid motion within the inner ear. Image taken by physiologist Jagger of University College London.



DAN JAGGER *UNIVERSITY COLLEGE LONDON EAR INSTITUTE*

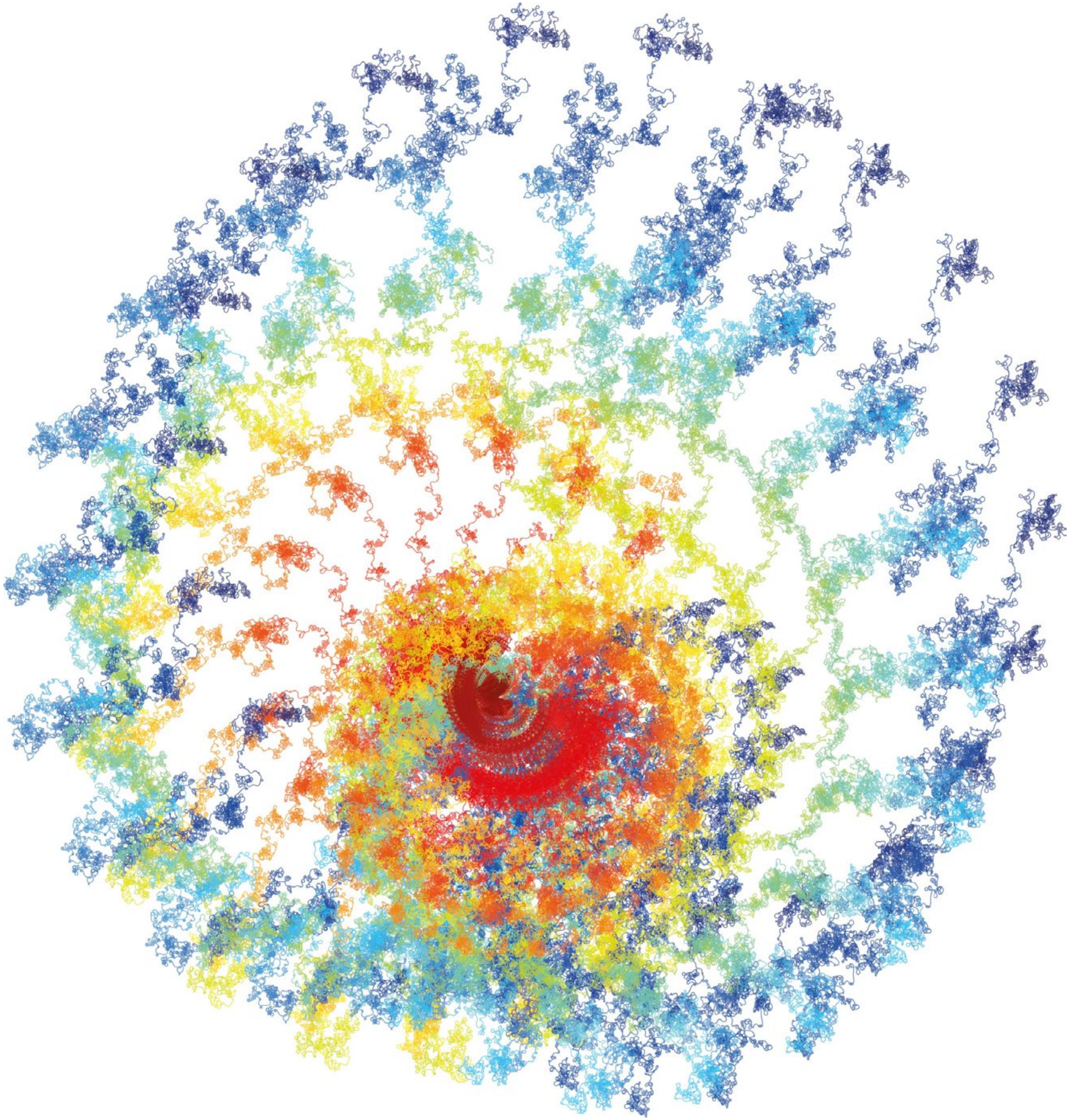
THE ART OF NEUROSCIENCE

Editor's Pick

The Walking Brain

By Michele Angelo Colombo

Neuroscientist and artist Colombo of the University of Milan in Italy plotted brain waves from an electroencephalogram (EEG) as a single dot moving across a two-dimensional plane. According to Colombo, the angular change between data points from the original EEG corresponds to a change in direction as the dot moves. This technique offers a new way to visualize and analyze data from EEGs.



MICHELE ANGELO COLOMBO *UNIVERSITY OF MILAN*

OPINION

Brian Solis is principal analyst and futurist at Altimeter and author of *Lifescale: How to Live a More Creative, Productive and Happy Life*.


GETTY IMAGES

OBSERVATIONS

The Death of Social Reciprocity in the Era of Digital Distraction

Honor your right to disconnect and focus on strengthening real relationships

You're walking along the street and bump into a friend. After a quick hello, this friend compliments you. What do you do in response? Most likely, offer a compliment in return. Or, at the least, say thank you.

A few steps farther down the street, you see someone drop a wallet. You pick it up and hand it to them. The person thanks you. Your response: "You're welcome."

For most of us, interactions throughout each day are filled with social reciprocity. It's instantaneous and second nature. Even chimps have been shown to engage in it. It can be a very good thing. But in recent years digital distraction has turned it into a problem.

As I explain in my book *Lifescale*, many creators of digital platforms have studied psychology. Their goal has been to eat up more and more of our days. Through persuasive design, they've worked to manipulate human behavior.

After all, the attention economy is wildly lucrative. Our attention is the currency; it's what we pay to use these platforms for free. It's also finite, so there's limited supply and great demand. Netflix CEO Reed Hastings once said his company's number-one competitor was sleep: "And we're winning!"

Having spent years in Silicon Valley as a digital futurist and adviser to many social media companies, I've seen the myriad ways the purveyors of these technologies work to get users addicted. They've been so successful that there's even a term for fear of being without your cell phone, "nomophobia." One trick that gets too little attention (pun intended) is the psychological hijack of social reciprocity.

In the digital world, interactions take place at an unprecedented pace. People like or share your posts and tag you in theirs. They send you connection requests or follow you and often expect you to do the same in return. Notifications show people when you have read their messages, so they might find it rude if you don't respond relatively soon. After you respond, you see those wavering dots of someone composing a reply to you, so you know the conversation is continuing.

All of this makes you feel anticipation and pressure to stay engaged, respond, check back and interact. *Vice* reported in 2017 that Snapchat's elongating red lines displaying "the number of days of since two users interacted" even reportedly led some teens to ask friends "to babysit their streaks"—that is, to interact on their behalf—while they were on vacation.

This is the new norm. We've been fooled into believing we're more connected, informed, productive, creative and happy. But in reality, this kind of social reciprocity eats away at our norms and values and rebuilds them in harmful ways. As a former Facebook executive put it, "The short-term, dopamine-driven feedback loops that we have created are destroying how society works."

I know from experience what a toll this can take. Several years ago I found myself struggling. I couldn't concentrate on work and often wasn't fully present with my family.

I was totally distracted, being drawn to notification after notification. I'd tell myself not to reach for my phone. But within minutes (or seconds), I'd nevertheless be checking out a picture that a friend just posted on Instagram and composing a response to let him know that I'd seen and enjoyed it.

A year went by before I realized I had to press pause on all of it. I wasn't just losing productivity but also my creative spark and even my ability to feel happiness. Worst of all, my relationships were suffering.

To tackle the part of your mind that feels—instinctively—that you owe it to people to reciprocate, I recommend two key steps:

1. HONOR YOUR RIGHT TO DISCONNECT.

In 2017 France officially gave workers the "right to disconnect" from e-mail after work hours.

What if we take that idea and broaden it out? We all have a right to disconnect from the bombardment of notifications. And that means we have a right to not reciprocate instantly to online interactions.

Thinking of it this way—as a right—can be psychologically empowering.

2. FOCUS ON STRENGTHENING REAL RELATIONSHIPS.

The other step is to focus on strengthening your relationships with those closest to you by carving out time for them.

In *Lifescale*, I explain the steps I took to overcome my tech addiction. One was to list the values most important to me and the actions I would take to honor them. As part of this, I vowed in writing to carve out uninterrupted time for family and help those relationships grow and thrive.

By keeping in mind that interaction online took time away from work or family, I learned to ease off the pressure of digital social reciprocity. I took back control.

So, yes, some people don't hear back from me as quickly as they used to. I hear all the time from people who are genuinely upset with me about that. But my personal life and career have never been better.

Ryan Bonnici is chief marketing officer of G2 and a board member of Bring Change to Mind.

OBSERVATIONS

Workers Are Afraid to Take a Mental Health Day

Bosses like me can fix that

On a recent morning, an employee came up to me. This employee was having either a panic attack or an anxiety attack (wasn't sure which), and needed to go take a mental health day. "Of course," I said. I canceled a meeting we had planned and put this employee's assignments on hold. My focus was to make sure the person was okay.

This was not the first time that a member of my team has taken a mental health day, and there's a reason my employees feel comfortable doing so: I've done it myself. Instead of simply calling out "sick," I've explicitly told my staff that I needed, and was taking, a day for my mental health.

The journey that got me to this point was a long one. Several years ago I would never have admitted having any mental challenges. And, sadly, I might have even silently judged other people negatively for having them.

I thought about this recently when Mental Health America published a disturbing but unsurprising statistic. In a survey of nearly 10,000 people, 55 percent agreed with the statement "I am afraid of getting punished for taking a day off to attend to my mental health."

This finding comes at a time when Americans are feeling more chronic stress, worry and anger, according to Gallup. In fact, Americans are now among the most stressed people in the world. The National Institute of Mental Health warns that stress carries mental health risks. Nearly 47 million U.S. adults—19 percent of the adult population—suffer from a mental illness.

Research in recent years even suggests that "almost everyone will develop at least one diagnosable mental disorder at some point in their life"—and that overall, the mental health of people across the U.S. may have declined over the past 20 years.

Businesses have not only a moral but also a financial incentive to make the mental health of their employees a priority. According to the World Health Organization, depression and anxiety alone cost the global economy $1 trillion a year in lost productivity. And Aetna reported recently that companies' annual expenses for mental health care are rising twice as fast as they are for all other medical expenses.

There's no question that teaching employees healthy habits can help change workplace culture around these issues. But my experience shows that the biggest, most important step business leaders can take is to open up about our own mental health in an honest way. This is particularly true for those of us in the C-suite. Ultimately, it's the only way to make clear to our employees that they are safe to do the same.

Unfortunately, bosses often have a very tough time confiding to anyone at all about their mental health struggles. As one psychologist told CNN, "A lot of CEOs are confident they can manage on their own, and they slip into overdrive."

Even if "executive stress"—the idea that business leaders are under more strain—is a myth, no leader wants to be seen as weak or to have people question their decisions based on a concern about their mind. So the stigmas around mental health challenges can prevent leaders from opening up.

It took an epiphany for me to change my ways. After a childhood filled with traumatic bullying, I became career-obsessed. When I achieved my biggest professional goal of becoming a CMO at the age of 29 and still couldn't feel happy, I realized something was wrong.

As I delved into therapy, I came to realize that I had ignored my own depression and anxiety because I was convinced they were forms of weakness. So I did a proverbial "180." I began not only embracing mental health but being open about it in the workplace. I include my therapy sessions on my calendar for everyone to see. I tell people about this journey.

A few months ago I told my direct reports, "Sorry for the late notice, but I'm canceling my meetings for today as I need to take a mental health day." Their responses were purely positive and supportive.

That helped open the door. Increasingly, my employees and people from outside my department have come to speak with me about what they're going through. I also hear from people at other companies all the time wanting to discuss their struggles.

No one, at any business, should feel afraid to take a mental health day. And no one should ever be punished for doing so (and if you are, it might be a sign to quit your job). As executives, we already have enough challenges before us. Let's not allow this to be one of them.

OPINION

Tam Hunt is a practicing lawyer (renewable energy law and policy) by day and by night a scholar (affiliated with the department of brain and cognitive sciences at the University of California, Santa Barbara) in the philosophy of mind, the philosophy of biology and the philosophy of physics.

OBSERVATIONS

Where's My Consciousness-ometer?

Whether an entity is conscious may soon be a testable question

How do you know your dog is conscious? Well, she wags her tail when she's happy, bounces around like a young human child when excited, and yawns when sleepy—among many other examples of behaviors that convince us (most of us, at least) that dogs are quite conscious in ways that are similar to, but not the same as, human consciousness.

Most of us are okay attributing emotions, desires, pain and pleasure—which is what I mean by consciousness in this context—to dogs and many other pets.

What about further down the chain. Is a mouse conscious? We can apply similar tests for "behavioral correlates of consciousness" such as those I've just mentioned, but for some of us, the mice behaviors observed will be considerably less convincing than for dogs in terms of there being

MARTIN BARRAUD *GETTY IMAGES*

an inner life for the average mouse. What about an ant? What behaviors do ants engage in that might make us think an individual ant is at least a little bit conscious? Or is it not conscious at all?

Let me now turn the questions around: How do I know you, my dear reader, are conscious? If we met, I'd probably introduce myself and hear you say your name and respond to my questions and various small talk. You might be happy to meet me and smile or shake my hand vigorously. Or you might get a little anxious at meeting someone new and behave awkwardly. All of these behaviors would convince me that you are in fact conscious much like I am and not just faking it!

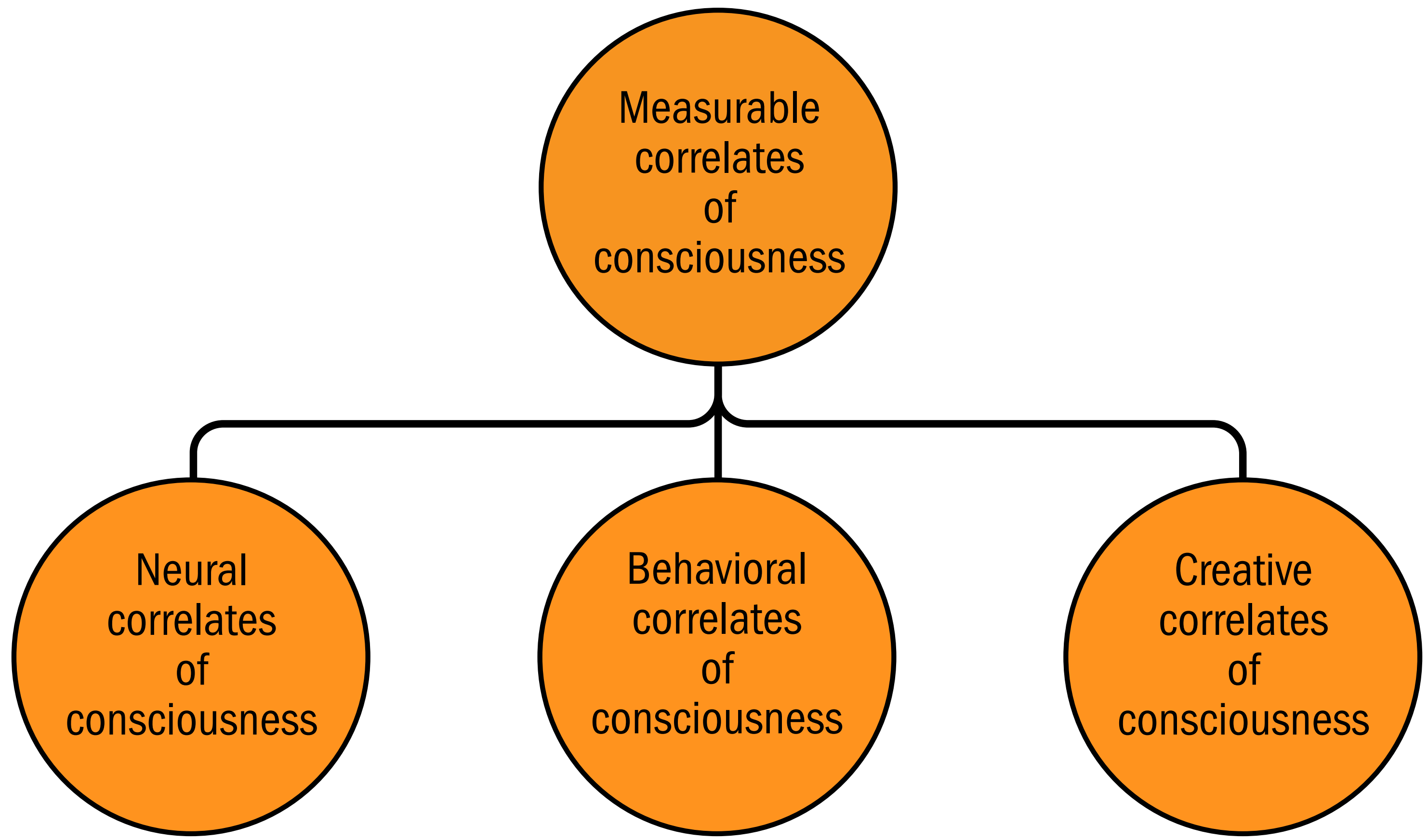
Now here's the broader question: How can we know anybody or any animal or any thing is actually conscious and not just faking it? The nature of consciousness makes it by necessity a wholly private affair. The only consciousness I can know with certainty is my own. Everything else is inference.

So, where's my consciousness-ometer?

These questions are more than philosophical. With the coming age of intelligent digital assistants, self-driving cars and other robots serving us and increasingly running our lives, does it matter if these AIs are actually conscious or just faking it?

Perhaps more relevant today, how can we know that coma victims or patients in vegetative or minimally conscious states are conscious or not?

This is an active area of research, and for the poor victims in these categories, plus their families and loved ones, these questions are deadly serious. How can a family know whether to take a patient off life support or not, if they don't know with any certainty what kind of consciousness is or is not present?



The various types of measurable correlates of consciousness.

In my work, often with psychologist Jonathan Schooler of the University of California, Santa Barbara, we're developing a framework for thinking about the many different ways to possibly test for the presence of consciousness—all using, necessarily, a process of reasonable inference.

There is a small but growing field looking at how to assess the presence and even quantity of consciousness in various entities. I've divided possible tests into three broad categories that I call the measurable correlates of consciousness, or MCC, as shown above.

Let's look at each of these categories in turn.

NEURAL CORRELATES OF CONSCIOUSNESS AND "SIGNATURES OF CONSCIOUSNESS"

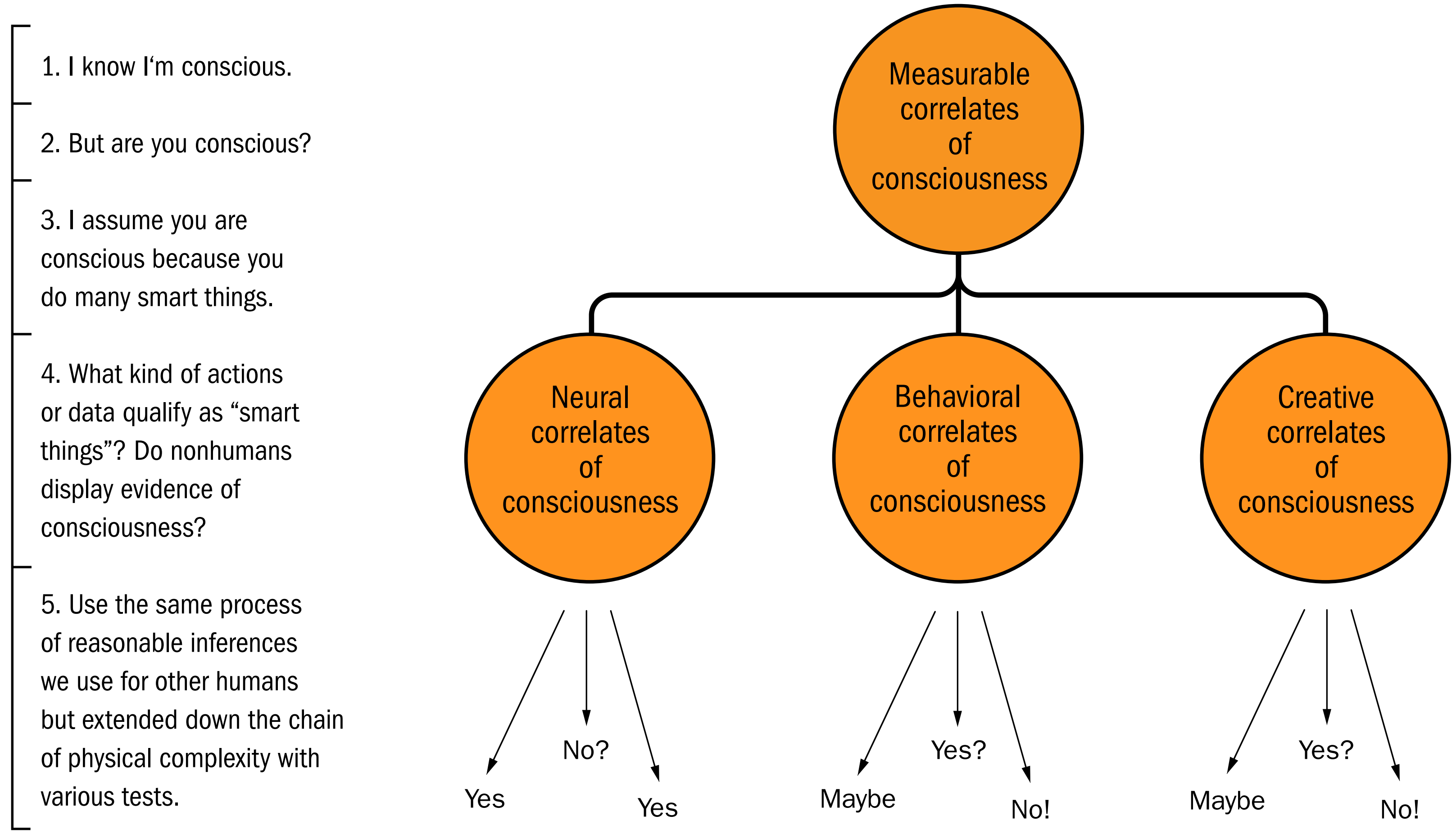
When determining whether a vegetative patient is conscious in any way, we can and do examine the neural correlates of consciousness only, because there aren't any behaviors to observe and no creative products either. Various researchers have proposed tests for cognition and consciousness in coma and vegetative patients.

TAM HUNT

What's physically going on in the brain? Neuroimaging tools such as EEG, MEG, fMRI and transcranial magnetic stimulation (each with their own strengths and weaknesses) are able to provide information on activity happening within the brain even in coma and vegetative patients.

Stanislas Dehaene, a French neuroscientist, has identified four "signatures of consciousness," which extend the idea of neural correlates of consciousness to more specific aspects of brain activity that are necessary for conscious awareness. He focuses on what's known as the "P3 wave" in the dorsolateral cortex as the single most important signature of consciousness in humans. And in tests of vegetative and minimally conscious patients, he and his colleagues have successfully predicted which patients are most likely to regain more normal states of consciousness.

Sid Kouider, another French neuroscientist, has examined very young babies to assess the likelihood of them being conscious. He concludes (unsurprisingly) that even newborns are conscious in various complex ways.



Summary of our approach for assessing the presence and nature of consciousness in any physical structures.

TAM HUNT

BEHAVIORAL CORRELATES OF CONSCIOUSNESS

When we are considering potential conscious entities that can't communicate directly and that won't let us put our neuroscientific measurement tools on their head (if they even have a head), we need to consider behavioral correlates as clues for the presence and type of consciousness.

For example, are cats conscious? The brain architecture in cats is quite different from humans, and they have very minimal prefrontal cortex, which is thought to be the center of many higher-order activities of the human brain. But is a prefrontal cortex necessary for consciousness?

Cat behavior is complex and pretty easy to map onto human behavior in many ways. The fact that cats purr, flex their toes and snuggle when petted, in similar ways to humans demonstrating pleasure when physically stimulated (minus the purrs, of course), meow loudly for food when hungry, and stop meowing when fed, demonstrate curiosity or fear about other cats or humans with various types of body language and many other behaviors that we can easily observe ourselves if we have cats as pets is all pretty convincing evidence, for most of us, that cats are indeed conscious and have a rich emotional life.

CREATIVE CORRELATES OF CONSCIOUSNESS

Creative output is another source of information for assessing the presence of consciousness. If for whatever reason we can't examine neural or behavioral correlates of consciousness, we may be able to examine the creative products of consciousness for clues.

For example, when we examine ancient architectural structures such as Stonehenge or cave paintings in Europe that have been judged to be as much as 65,000 years old, are we reasonable in judging the creators of these items to be conscious in ways similar to our own? Most of us would say: obviously, yes. We know from experience that it would take high intelligence and consciousness to produce such items today, so we reasonably conclude that our ancient ancestors had similar levels of consciousness.

What if we find obviously unnatural artifacts on Mars or other bodies in our solar system? Do we reasonably infer that whatever entities created such artifacts were conscious? It will depend on the artifacts in question, but if we were to find anything remotely similar to human dwellings or machinery on other planets but that was clearly not human in origin, most of us would reasonably infer that the creators of these artifacts were also conscious.

Closer to home, artificial intelligence has produced some pretty impressive art, fetching more than $400,000 at a recent art auction. At what point do reasonable people conclude that amazing art creation requires consciousness? We can conduct a kind of "artistic Turing test" and ask study participants to consider various works of art and say which ones they conclude must have been created by a human. And if AI artwork consistently fools people into thinking it was made by a human, is that good evidence to conclude that the AI is at least in some ways conscious?

There is not yet a consciousness-ometer, but various researchers have suggested ideas, including Dehaene and Italian-American researcher Giulio Tononi and his colleagues, who focus on "integrated information" as a measure of consciousness.

Tononi and his colleagues, such as Christof Koch, focus on what they call "integrated information" as a measure of consciousness. This theory suggests that anything that integrates at least one bit of information has at least a tiny amount of consciousness. A light diode, for example, contains just one bit of information and thus has a very limited type of consciousness. With just two possible states, on or off, however, it's a rather uninteresting kind of consciousness.

In my work, my collaborators and I share this "panpsychist" foundation. We accept as a working hypothesis that any physical system has some associated consciousness, however small it may be in the vast majority of cases.

Rather than integrated information as the key measure of consciousness, however, we focus on resonance and synchronization and the degree to which parts of a whole resonate at the same or similar frequencies. Resonance in the case of the human brain generally means shared electric field oscillation rates, such as gamma band synchrony (40 to120 hertz) as one example.

Our consciousness-ometer would, insofar as it focuses on neural correlates of consciousness, look at the degree of shared resonance of various types, and resulting information flows, as the measure of consciousness. Humans and other mammals enjoy a particularly rich kind of consciousness because there are many levels of pervasive shared synchronization throughout the brain, nervous system and body.

In our framework more generally, we propose a "weight of the evidence" approach to assessing the presence and nature of consciousness in any particular object of study. We put a number of questions, in all areas of MCC as described above, to the object of study, and it answers in whatever ways it can. We then make the same kinds of reasonable inferences about the presence and nature of consciousness that we do every day when it comes to other humans or animals. This questioning process is meant to be truly general and could apply to any object of study.

The logical chain of this framework is straightforward: I know I'm conscious; I assume you are conscious because you act a lot like me and do many smart things; I engage in similar reasonable inferences when assessing whether various animals are conscious and to what degree; we can use the same process of reasonable inference all the way down the chain of physical complexity. The graph on page 62 summarizes this approach.

Tests for consciousness are still in their infancy. But this field of study is undergoing a renaissance because the study of consciousness more generally has finally become a respectable scientific pursuit. Before too long it may be possible to measure just how much consciousness is present in various entities—including in you and me.

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OBSERVATIONS

Which Weighs More: A Pound of Stone or a Pound of Styrofoam?

It's not a trick question: your brain answers differently depending on whether they're part of the same object or not

GETTY IMAGES

For more than a century, scientists thought they knew the answer to a curious question: why does 10 pounds of a low-density substance such as Styrofoam feel heavier than 10 pounds of stone? It isn't heavier, of course, but repeated experiments have shown that it feels that way.

Now psychologists say their initial explanation may have been incomplete, and the new explanation could have far-reaching consequences, including for the way Netflix designs the algorithms that recommend movies to its customers.

Scientists have known for decades that when asked to lift two objects that seem like they should have different weights but are actually equally heavy, people will say the lighter-looking one feels heavier. Experts believed this illusion, called the material-weight illusion, occurs when the brain's expectations about weight are contradicted: Throughout life we learn through experience that some materials are heavy and others are light. Over time we become skilled at guessing an object's weight from its appearance alone.

But new evidence suggests that the brain bases some guesses on how weight is distributed across an object. In a recent study scientists looked at how people perceived the weight of a block made of two materials. A team led by Roland Fleming, a psychologist at the University of Giessen, created blocks composed of two halves that appeared to be made of materials with different densities and thus could be expected to have different weights: stone, wood or Styrofoam. The team asked people to lift a block made of two of these materials (such as stone paired with Styrofoam) and rate the relative weight of each side of the block.

But here's the trick: both halves of the block actually had the same weight. Before the experiment, the scientists had secretly carved out the inside of the block and filled the cavity with lead to create an even weight distribution. The scientists wanted to know whether people would be tricked by the material-weight illusion and report that the lighter-looking side of the block felt heavier. The results took the scientists by surprise: When handling these two-material blocks, people said that the heavier-looking side felt heavier. That is the opposite of what the scientists expected based on what they knew about the material-weight illusion for uniform objects.

So what causes people to perceive weight differently in some situations?

Fleming's team says it's all about context. In traditional experiments with objects made of one material, the brain makes a guess based on its prior knowledge and compares its guess with the actual weight that the body feels when lifting each object. If the body's experience contradicts the brain's guess, the brain cannot reconcile its prediction with the actual weight, so it throws the body's observation out. The brain assumes that particular Styrofoam block must just be especially heavy—so heavy, in fact, that the brain thinks it's heavier than a stone block, even if the blocks actually have the same weight.

But Fleming and his colleagues think that when people focus on the weight distribution of an object made of two materials, the brain calculates weight in another way. Instead of throwing the body's observation out, the brain concludes that each side's weight lies between the initial guess and the actual weight. If the brain expects stone to feel heavier than Styrofoam but the two actually have equal weights, the brain combines these two pieces of information and decides that the stone side still feels heavier, although not as heavy as originally thought.

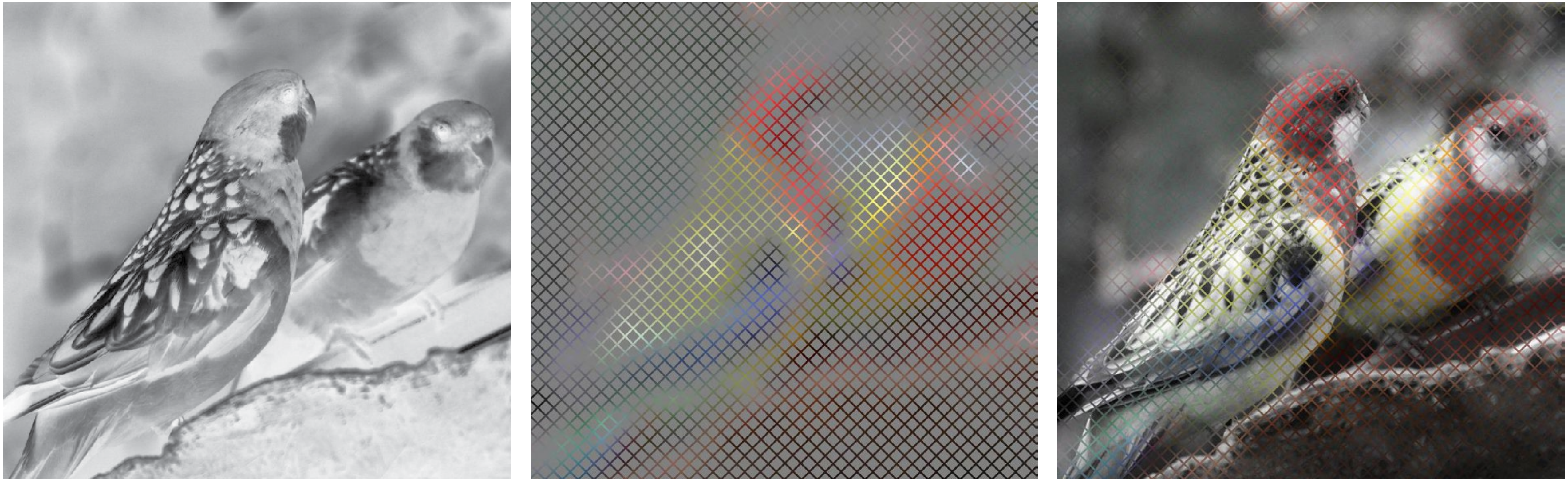
The scientists reason that the brain does this because it disagrees with the body differently in the two situations. When a person lifts a deceptively heavy object, the brain and body are in conflict because the brain is not equally good at using what the body feels to estimate weight and weight distribution. This variation in accuracy between the uniform-weight and weight-distribution tasks causes people to perceive weight differently in the two situations.

Knowing how the brain estimates weight isn't just an interesting experiment—it can actually help scientists develop smarter technologies that we use every day. Now that we know more about how context changes the brain's decisions, programmers might be able to update technologies such as Netflix to imitate the brain more accurately and provide more fine-tuned recommendations for users. Netflix already recommends new shows on the basis of what users have watched previously, but now developers might be able to tell the algorithm to weigh several situational factors when deciding which show to recommend next.

For example, Netflix could consider factors such as the time of year and how much time has passed since your last viewing session to assess your viewing habits more reliably. This means less time browsing and more time enjoying a new show that fits your preferences.

So the next time you sit down for an evening of streaming, notice what the site recommends. You might see the effects of context in action.

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*.



Steven Dakin's illusory coloring of a grayscale image of eastern rosellas (original from www.animal.photos.com).

Chasing Rainbows

Black-and-white photos turn into Technicolor

In July the Internet exploded with a photo of schoolchildren. The kids, dressed in dark shorts and colorful T-shirts, appear to be enjoying a field trip, perhaps to a zoo or a nature preserve. In the center of the image, a crouching girl in a yellow T-shirt holds a medium-sized turtle toward an adult taking a picture of the scene. Smiling classmates, dressed in matching white, green, red and blue T-shirts, gather around the girl and turtle. At first sight, nothing seems amiss in the group shot. But a closer examination reveals that the many hues in the background and the children's clothing are not real colors. The seemingly polychromatic image is actually black-and-white, overlaid with a thin multicolored grid.

Dubbed the "color assimilation grid illusion" by its creator, digital media artist and software developer Øyvind Kolås, the artifice is related to other visual effects evoking illusory tints, such as the Munker illusion, neon color spreading and the watercolor illusion. Such colorful deceptions occur because our brain's visual system processes color at much lower resolution than it does shape.

Pastel and watercolor painters from Cezanne to Picasso have taken advantage of our coarse color perception to do away with coloring inside

STEVEN DAKIN

the lines. Instead artists often apply pigment to objects and people in a vague, imprecise way, without paying much mind to depicted boundaries. The visual brain, unfazed, assigns the correct colors to the relevant shapes, and observers are none the wiser.

The crisscrossing grid in the original image is not critical to the misperception. Neither is the particular image that went viral. Kolås has shown similar effects with many other grayscale pictures, by virtue of superimposing on them colored lines, polka dots and even text. The images in this column illustrate how a delicate chromatic grid, overlaid on a black-and-white photo of two eastern rosellas (Australian parakeets), restores the birds' dazzling tones to our perception.

SCIENTIFIC AMERICAN MIND

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