SEPTEMBER 2023

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The Science of Narcissism

Deep-Sea Mining

How AI Learns What No One Taught It

Dinosaur Giants

How the biggest animals ever to walk Earth got so huge


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SCIENTIFIC AMERICAN

ON THE COVER

Argentinosaurus is the biggest definitive sauropod dinosaur on record. It weighed an estimated 75 metric tons. Sauropods attained the largest sizes of all terrestrial animals, and they evolved these supersized proportions again and again over the course of their 150-million-year history. New research hints and how—and why—they became giants. Illustration by Chase Stone.

Photograph by Vincent Fournier

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Bob Staake
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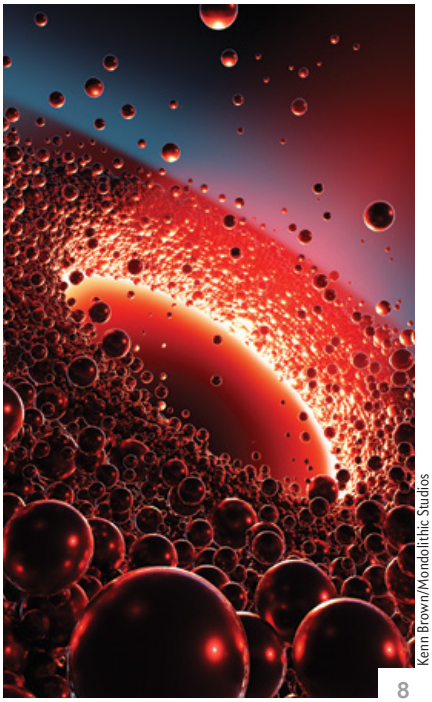
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Laura Helmuth is editor in chief of *Scientific American*.
Follow her on Twitter @laurahelmuth

Living Large

Do you know someone who is a narcissist? You probably do—an estimated 6 percent of the population has at some point fit the criteria for narcissistic personality disorder. It's a difficult condition to diagnose, in part because many people who have it think they're just fine (or exceptional) the way they are, and they don't seek help. The researchers who study the condition and the therapists who treat it tend to disagree about some of the fundamental characteristics of narcissism. They agree that there seem to be two main expressions of narcissism: grandiosity and vulnerability. They disagree about whether these two primary characteristics always overlap or whether grandiosity can exist on its own. As writer Diana Kwon explains on page 52, new research, including brain imaging, is starting to resolve some of the big questions about narcissism.

Sauropods, like narcissists, are difficult to study. You'd think the largest land animals in the history of Earth would be prominent in the fossil record, but their bones tended to scatter, and it's tough to get a lot of data when each femur requires a forklift to move. (In case you're wondering, blue whales are almost as long as the longest sauropods, but they weigh much more because the effect of gravity is different in water.) Paleontologist Michael D. D'Emic recently analyzed sauropod size around the world and found that different lineages evolved into giants three dozen times. In our cover story starting on page 26, he theorizes about how and why they grew so big. Enjoy the many dino illustrations included.

One thing I think all of us at *Scientific American* love about our jobs is that we learn something new every day. I hadn't known about the Clarion-Clipperton Zone (CCZ) of the Pacific before this issue, for example, but we could all be hearing much more about it in the next year. Deep-sea mining operations want to harvest the CCZ's potato-size nodules containing valuable metals. The problem is that the CCZ is pristine, barely explored and full of unknown species that could be valuable in their own right. Scientists are rushing to understand the ecosystem and the potential impacts of mining, as journalist Olive Heffernan shares on page 34, and the International Seabed Authority has to decide soon whether to allow massive dredging of this unique environment.

Artificial-intelligence systems also learn, in a way—and it's a way we don't entirely understand. As *Scientific American* contributing editor George Musser describes on page 58, AIs seem to build a model of the world. This representation allows them to make connections and express knowledge that goes well beyond what they were trained to do. Stay tuned.

Dementia can increase the risk of criminal behavior, and the justice system is poorly equipped to handle such cases. On page 62, writer Jessica Wapner narrates the story of one defendant who did the crime (health-care fraud)—but to what extent was he responsible? Some experts are calling for a special court system for people with cognitive decline, modeled on the juvenile justice system.

Some of the most spectacular stars in the universe are called Wolf-Rayets. They're enormous, hot, rare and dramatic—the final stage in an enormous star's fast-burning life before it goes supernova. Astronomer Peter Tuthill (*page 44*) has found some fascinating Wolf-Rayets, and he and his colleagues are now using James Webb Space Telescope images to understand their fine structure and fate.

Here's some great news as we head into the fall: vaccines for respiratory syncytial virus, or RSV, are now available for older adults, and new treatments are available for infants. On page 70, journalist Tara Haelle spells out the history of research that led to these advances. RSV is a nasty virus that kills more than 14,000 people in the U.S. every year, and we hope this work will save many lives. SA

Illustration by Nick Higgins


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can more women
drive innovation in
our industry?
Women continue to be underrepresented in fields such as science, technology, engineering and math.
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April 2023

PHYSICS PIONEER

"A Hidden Variable behind Entanglement," Michelle Frank's article on physicist Chien-Shiung Wu's early work on entanglement, was such an amazing story and so beautifully written. Wu's contribution to science despite the challenges she faced for recognition and career progression is so inspirational. The photograph of her sitting in the front row at a particle physics conference really got me. Powerful stuff.

Jacqui Gilmour *via e-mail*

Thank you for Frank's revealing article on our society's gender bias against Wu. The article states that she boarded a ship for California in 1936 and that "at the University of California, Berkeley, Wu became a star student." But an accompanying photograph of her immigration file shows that her visa stated she would "pursue a course in Physics at the University of Michigan." Is this early evidence of entanglement at a distance? As the proud parent of a Michigan grad, I would also ask if it is a demonstration of parity breaking.

John D. Foote *via e-mail*

FRANK REPLIES: Thank you so much for the kind words! Before leaving China, Wu had been accepted to the University of Michigan, and this is why her immigration paperwork included the details Foote noticed. When Wu arrived in California, however, she decided to transfer to U.C. Berkeley. My editor, Jen Schwartz, and I decided not to include that change of plans in this article simply for space reasons and to keep the narrative moving. There is a layered story about why Wu changed her mind, though. It involves allegations of gender discrimination at the University of Michigan's student union and an informal campus tour of U.C. Berkeley's world-class physics department. That tour was led by Luke Chia-Liu Yuan, the man whom Wu would later marry. Whether Yuan himself or the prospect of access to a cyclotron had a greater influence on Wu's transfer decision remains open to debate!

"Physicist Chien-Shiung Wu's contribution to science despite the challenges she faced is so inspirational."

Jacqui Gilmour *via e-mail*

FALSE TALK

I am deeply disturbed by "Chatbots Talking," Giacomo Miceli's article on how he created an artificial-intelligence-generated conversation between two real people who did not actually have that discussion. "I built this conversation as a warning," he writes, and so it is. The easy, quick, inexpensive and very available method of voice cloning using AI will have enormous impact on all societies around the world. Because synthetic voices and the conversations they engage in can be so convincingly real and natural, this technology's opportunity for abuse is unimaginable.

The thing that bothers me most is that voice and video manipulation will bring about a crisis in trust, as the author mentions. How will we trust that the "recording" of a politician, a judge, a law-enforcement officer, a witness in a trial, a doctor or anyone in a position of power is genuine? We are totally unprepared to meet this challenge.

Robert Walty *Stephens City, Va.*

YOU'VE GOT TO BE KIND

In "Kindness Goes Farther Than You Think" [Mind Matters], Amit Kumar describes how small acts of kindness can have a large impact on recipients' moods. When I read the article, I was reminded of special moments in my life: Last winter in a tiny Mexican fishing village, I gave a bilingual edition of *Curious George* to a seven- or eight-year-old boy. Later he was seen clutching his treasured book to his chest. When I gave a Spanish version of "The Little Mermaid" to a young girl, she wouldn't stop hugging me. What joy for both of us! Next winter I will spread even more joy with classic picture books for the children.

Merilyn Grosshans *Las Vegas, Nev.*

OPEN CONTEMPT

"Why People Hate Open Offices," by George Musser, makes a number of interesting points about the health and productivity problems created by such designs. It fails, however, to mention the worst plan of all: a hybrid in which openness at the center of the floor is encircled by traditional window offices for management, with senior management in the highly desirable corner offices. The message couldn't be clearer: there's a strict hierarchy here, and you peons in the middle are at the absolute bottom.

John Sechrist *Pittsburgh, Pa.*

RULES OF RESPECT

In "Beyond the Golden Rule" [The Science of Health, February], Claudia Wallis argues that in life-or-death cases, physicians should not follow the Golden Rule and decide on patient care according to what they would want if they had the patient's condition. Instead they should follow the "platinum rule": the patient's autonomy (self-rule) should be respected, and the physician should make decisions in line with the patient's own wishes.

I agree that the patient's own wishes must be respected. But the author is misled in her application of the Golden Rule when she suggests that it does not apply in cases of quality-of-life decisions. An alternative interpretation would apply the Golden Rule as follows: "Respect the patient's autonomy as you would want your own autonomy to be respected in the same circumstances."

Don E. Scheid
Emeritus professor of philosophy, Winona State University, Minnesota

Thank you for publishing Wallis's article about the Golden Rule and the platinum rule. The latter should have a place in every doctor's education.

My husband, not knowing the platinum rule even existed, insisted on his doctors listening to him. We had a marvelous palliative care doctor who did listen and gave him the satisfaction of a peaceful end. Too often doctors apply their rules. They need to learn how to step back and let the patient and patient's family tell them what is wanted without bias.

Nan Sopin *via e-mail*

SEMANTICS OF FUEL

As someone who works in thought leadership across the public sector, I often point out how language around "climate disruption" conveys the wrong meaning, eliciting ineffective ways of addressing the problem. Semantics are very important, as Susan Joy Hassol tells us in "Changing the Language of Climate Change" [February].

I would only add "fossil fuels" to Hassol's list of terms that could be replaced with a better description. We can use "dirty fuels" instead. Both my five- and seven-year-olds have a fascination for fossils. "Fossil" evokes something cool, discovery, science—largely a positive meaning. I'm afraid that by repeating the term "fossil fuels," we are unintentionally passing the positive meaning to the whole dirty fuel industry.

Luis Sena Esteves
Melbourne, Australia

MOURNING RITUAL

I wish to express my appreciation for Piers Vitebsky's report on the Sora spiritual tradition of "Dialogues with the Dead" [January]. Vitebsky has managed to express in a beautiful way the human drama of losing these spiritually valuable customs. He has also put this into the perspective of the problems of present society.

Luigi Cavaleri
Institute of Marine Sciences, Italy

ERRATUM

"Blame Game," by Lois Parshley [June], should have said that Friederike Otto is now a senior lecturer in climate science at Imperial College London, not a professor of global climate science at the University of Oxford.

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Safeguarding AI Is Up to Everyone

The use of artificial intelligence is so varied and industry-specific, no one federal agency can manage it alone

By the Editors

Artificial intelligence is everywhere, and it poses a monumental problem for those who should monitor and regulate it. At what point in development and deployment should government agencies step in? Can the abundant industries that use AI control themselves? Will these companies allow us to peer under the hood of their applications? Can we develop artificial intelligence sustainably, test it ethically and deploy it responsibly?

Such questions cannot fall to a single agency or type of oversight. AI is used one way to create a chatbot, it is used another way to mine the human body for possible drug targets, and it is used yet another way to control a self-driving car. And each has as much potential to harm as it does to help. We recommend that all U.S. agencies come together quickly to finalize cross-agency rules to ensure the safety of these applications; at the same time, they must carve out specific recommendations that apply to the industries that fall under their purview.

Without sufficient oversight, artificial intelligence will continue to be biased, give wrong information, miss medical diagnoses, and cause traffic accidents and fatalities.

There are many remarkable and beneficial uses of AI, including in curbing climate change, understanding pandemic-potential viruses, solving the protein-folding problem and helping identify illicit drugs. But the outcome of an AI product is only as good as its inputs, and this is where much of the regulatory problem lies.

Fundamentally, AI is a computing process that looks for patterns or similarities in enormous amounts of data fed to it. When asked a question or told to solve a problem, the program uses those patterns or similarities to answer. So when you ask a program like ChatGPT to write a poem in the style of Edgar Allan Poe, it doesn't have to ponder weak and weary. It can infer the style from all the available Poe work, as well as Poe criticism, adulation and parody, that it has ever been presented. And although the system does not have a telltale heart, it seemingly learns.

Right now we have little way of knowing what information feeds into an AI application, where it came from, how good it is and if it is representative. Under current U.S. regulations, companies do not have to tell anyone the code or training material they use to build their applications. Artists, writers and software engineers are suing some of the companies behind popular generative AI programs for turning original work into training data without compensating or even acknowledging the human creators of those images, words and code. This is a copyright issue.

Then there is the black box problem—even the developers don't quite know how their products use training data to make decisions. When you get a wrong diagnosis, you can ask your doctor why, but you can't ask AI. This is a safety issue.

If you are turned down for a home loan or not considered for a job that goes through automated screening, you can't appeal to an AI. This is a fairness issue.

Before releasing their products to companies or the public, AI creators test them under controlled circumstances to see whether they give the right diagnosis or make the best customer service decision. But much of this testing doesn't take into account real-world complexities. This is an efficacy issue.

And once artificial intelligence is out in the real world, who is responsible? ChatGPT makes up random answers to things. It hallucinates, so to speak. DALL-E allows us to make images using prompts, but what if the image is fake and libelous? Is OpenAI, the company that made both these products, responsible, or is the person who used it to make the fake? There are also significant concerns about privacy. Once someone enters data into a program, who does it belong to? Can it be traced back to the user? Who owns the information you give to a chatbot to solve the problem at hand? These are among the ethical issues.

The CEO of OpenAI, Sam Altman, has told Congress that AI needs to be regulated because it could be inherently dangerous. A bunch of technologists have called for a moratorium on development of new products more powerful than ChatGPT while all these issues get sorted out (such moratoria are not new—biologists did this in the 1970s to put a hold on moving pieces of DNA from one organism to another, which became the bedrock of molecular biology and understanding disease). Geoffrey Hinton, widely credited as developing the groundwork for modern machine-learning techniques, is also scared about how AI has grown.

China is trying to regulate AI, focusing on the black box and safety issues, but some see the nation's effort as a way to maintain governmental authority. The European Union is approaching AI regulation as it often does matters of governmental intervention: through risk assessment and a framework of safety first. The White House has offered a blueprint of how companies and researchers should approach AI development—but will anyone adhere to its guidelines?

Recently Lina Khan, Federal Trade Commission head, said based on prior work in safeguarding the Internet, the FTC could oversee the consumer safety and efficacy of AI. The agency is now investigating ChatGPT's inaccuracies. But it is not enough. For years AI has been woven into the fabric of our lives through customer service and Alexa and Siri. AI is finding its way into medical products. It's already being used in political ads to influence democracy. As we grapple in the judicial system with the regulatory authority of federal agencies, AI is quickly becoming the next and perhaps greatest test case. We hope that federal oversight allows this new technology to thrive safely and fairly. SA

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Olivia Lanes is North American lead of IBM Quantum Community. She also sits on the National Q-12 Education Council, which focuses on workforce development at a national level. Lanes holds a Ph.D. in quantum physics.

Quantum Physics for K–12

To create a tech-literate workforce, schools need to teach quantum computing sooner

By Olivia Lanes

The harnessed power of the subatomic world could soon upend the modern computing industry. Quantum computers are all over the news, and fundamental work on the theory that gave rise to them won last year's Nobel Prize in Physics.

One place you might not hear about them is inside a high school physics classroom. But if we want to have any hope of developing a tech-savvy workforce for this emerging field, that needs to change.

Unlike the computer at your desk, which encodes words or numbers as collections of ones and zeros called "bits," quantum computers rely on quantum bits, or "qubits." Qubits can take on zero and one simultaneously during a calculation and interact via the probabilistic mathematical rules of quantum physics rather than classical logic. Researchers hope this novel computing architecture will significantly speed up certain hard problems such as factoring gargantuan numbers, which could take a regular computer billions of years to perform but a quantum computer just a few days.

This way of computing could open new frontiers in drug discovery or artificial intelligence, for example. But rather than exposing students to quantum phenomena, most physics curricula today start with concepts such as strings on pulleys and inclined planes. Quantum concepts end up in the realm of higher-level studies.

Technology demonstrations from IBM (my employer), Google and other industry players prove that useful quantum computing is on the horizon, and demand for quantum-savvy scientists is already skyrocketing. Yet a recent McKinsey report predicted that major talent shortages will persist for years, with as much as 50 percent of quantum job openings potentially going unfilled. McKinsey also estimated that the U.S. will fall behind China and Europe in building a quantum talent pool. China has announced the most public funding for quantum computing of any country to date, more than double the investments by European Union governments and eight times more than the U.S. government.

Thankfully, things are changing. Universities are exposing students sooner to once feared quantum mechanics courses. Students are learning through less traditional means, such as YouTube channels and online courses, and seeking out open-source communities to begin their quantum journeys.

In recent years the University of Wisconsin–Madison and the University of California, Los Angeles, have welcomed inaugural classes of quantum information master's degree students into yearlong programs. The University of Pittsburgh has launched an undergrad major that combines physics and computer science, answering the need for four-year programs that prepare students for either quantum employment or more education. Ohio has become the first state to add quantum training to its K–12 science curricula.

And universities around the world are beginning to teach courses using Qiskit, Cirq and other open-source quantum programming frameworks that let their students experiment on real quantum computers through the cloud.

What can really be gained by trying to teach quantum physics to students so young? Quantum is more than just a technology; it's a field of study that undergirds chemistry, biology and engineering. Quantum computing education *is* STEM education, as Charles Tahan, director of the National Quantum Coordination Office, once told me. Quantum computing students might work in a related field, such as fiber optics or cybersecurity, that would benefit from their knowledge of quantum programming or in a business where they can make better decisions based on their understanding of the technology.

Quantum overturns our perception of reality. It draws people in and keeps them there, as the popularity of NASA and the moon landing did for astrophysics.

For schools adapting to the emerging quantum era, don't underestimate your students. Universities should introduce quantum information sooner; K–12 schools should not shy away from teaching some basic quantum concepts to younger kids. We should lean into what captures students' attention and shape our programs to meet these desires—and prepare new generations for the quantum future. SA

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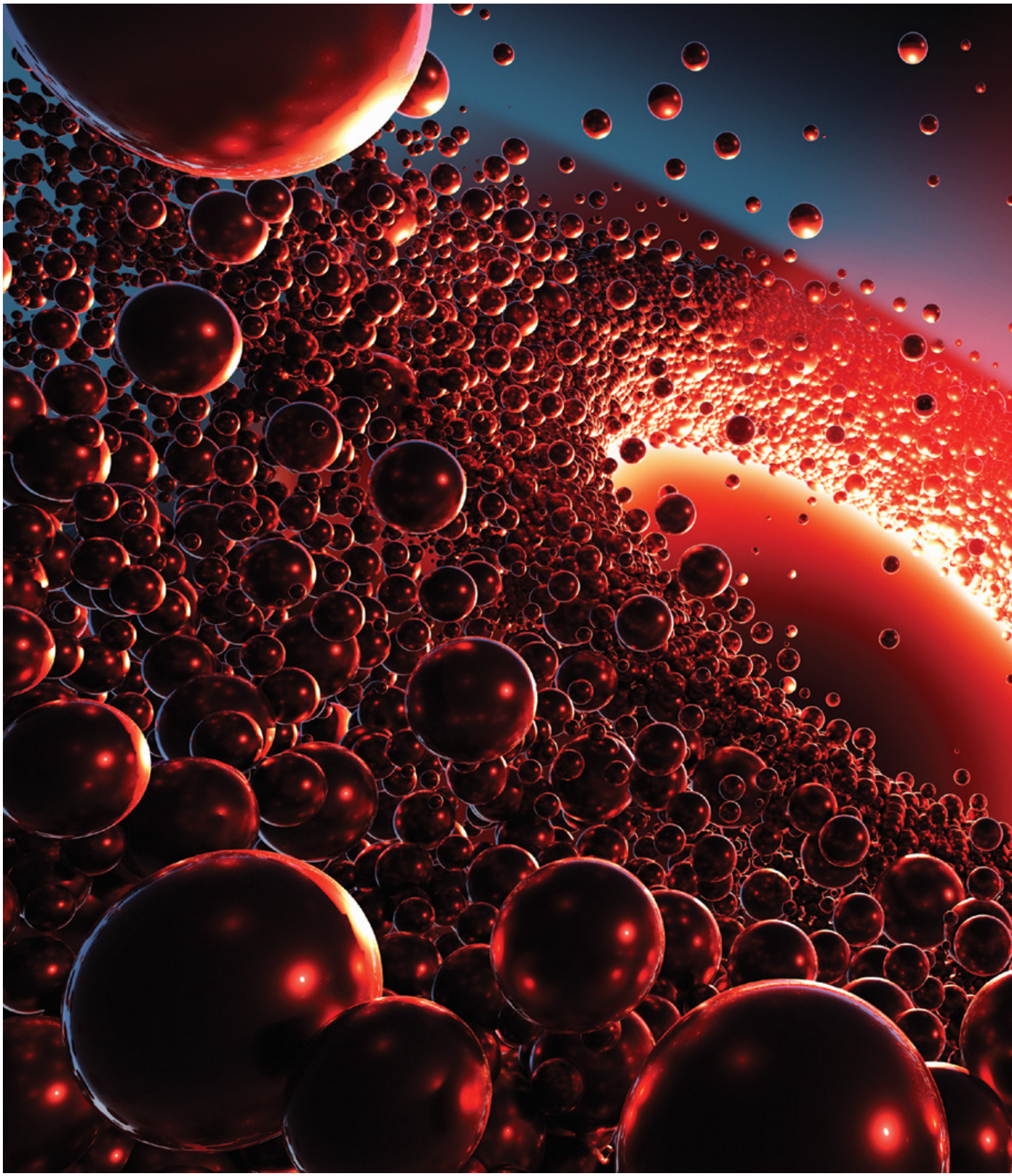

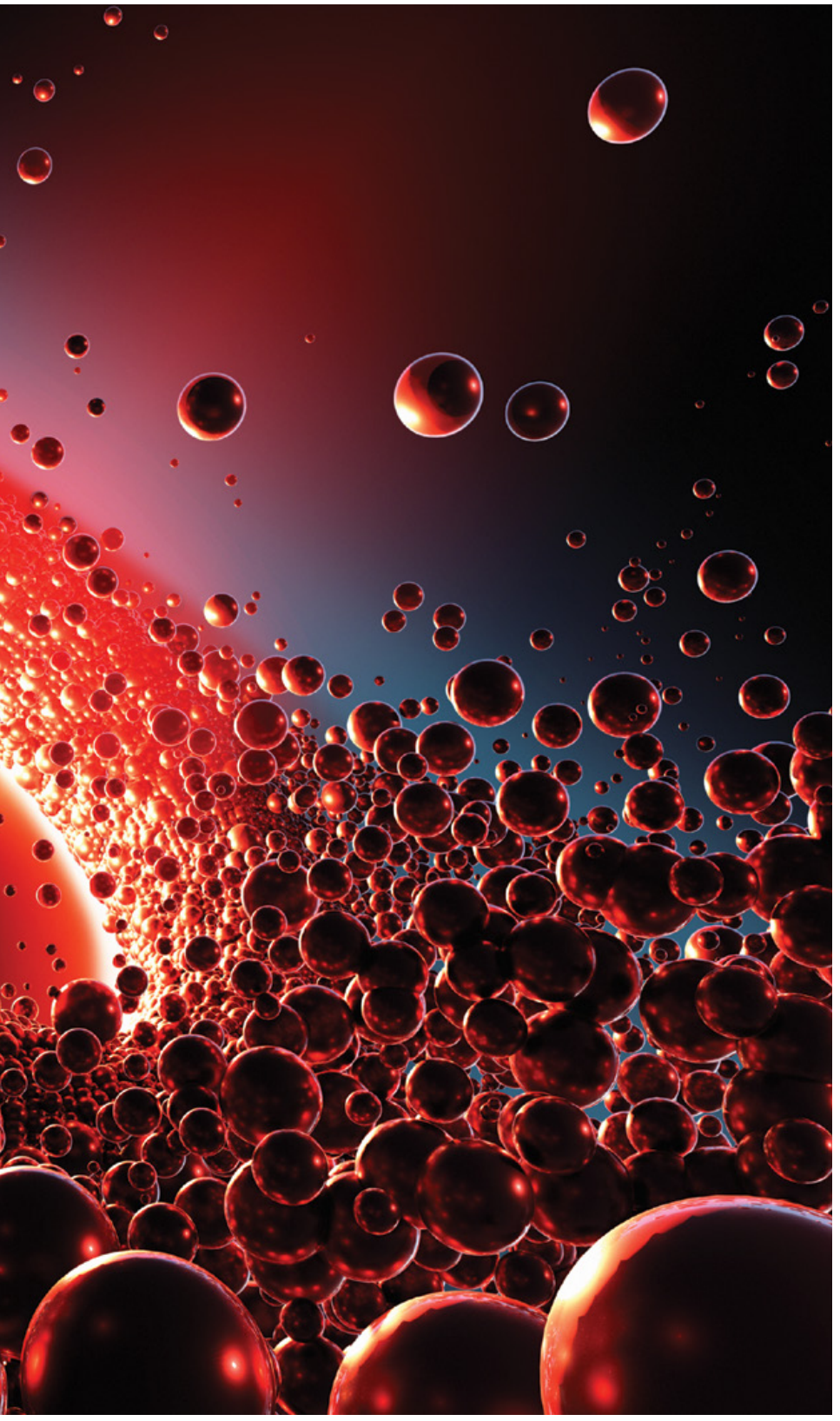

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INSIDE

ASTROPHYSICS

Disappearing Act

Black holes eventually evaporate—and everything else might, too

Stars, planets, people and petunias: everything emits a special kind of radiation and will, if it sticks around long enough, evaporate into nothing.

That's the claim in a new study of physics effects that were previously thought to occur only near a black hole. In that extreme environment, some of the largest and smallest things in the universe rub up against one another. To describe events on such different scales, scientists must use both Einstein's theory of relativity (rules governing the big stuff) and quantum mechanics (rules for itty-bitty things), leading to some outlandish effects. But if the new calculations are correct, such evaporation may be commonplace—even when black holes aren't around.

In the 1970s the late British physicist Stephen Hawking began thinking about what happened to particles that experienced the unparalleled gravitational forces at the edge of a black hole, a place known as the event horizon. Anything slightly inside the event horizon will unavoidably fall into the black hole, whereas anything just outside it still has a chance to escape.

Hawking wanted to know what would happen to pairs of particles—a particle and its antiparticle partner—that spontaneously appeared near a black hole's event horizon. These couplets emerge from the "empty" vacuum of space, and quantum mechanics tells us they constantly wink in and out of existence everywhere. As soon as a particle meets up with its antiparticle, they destroy each other in a fraction of a second, and the universe at large doesn't notice their presence.

Hawking showed that if one of the partners appeared within the event horizon, however, it would fall into the black hole while its associate on the horizon's other side would fly outward at tremendous speed. To conserve the total energy of the black hole and abide by a tenet of physics, the infalling particle must carry negative energy (and hence negative mass), and the launched one must have positive energy. In this way, black holes emit a type of energy now called Hawking radiation, and over time this escaping positive energy depletes them, causing them to evaporate.

About six years ago astrophysicist Heino Falcke of Radboud University in the Netherlands started thinking more deeply about the physics involved in these processes—and whether the black hole's event horizon was a necessary component. In other words, could this same evaporation occur with other objects? "I asked a few experts and got very different answers," he recalls.

Falcke enlisted the help of quantum physicist Michael Wondrak and mathematician Walter van Suijlekom, both at Radboud, to take another look at the issue. The trio decided to approach the topic from an atypical angle. The scientists used equations from a related phenomenon known as the Schwinger effect, which describes how charged particles and antiparticles get torn apart when they emerge from the vacuum in the presence of a powerful electromagnetic field. The process could be considered analogous to particle pairs experiencing strong gravitational forces at a black hole's event horizon.

The researchers' mathematical analysis showed how any object with mass—and not just a superheavy one such as a black hole—affects the pairs of particles and antiparticles that emerge from the vacuum of space. In more wavelike terms, these particles can be thought of as having a cloud of probability regarding where they might be located in space, says Tyler McMaken, a Ph.D. student who studies theoretical astrophysics at the University of Colorado Boulder. In the absence of any external forces, electromagnetic or gravitational, the clouds of both the particle and the antiparticle will overlap, and they will annihilate each other. But if gravity or some other force tugs on one cloud more than the other, each will be shifted slightly. They won't overlap and therefore won't be annihilated. Instead they will produce radiation, much like a particle that gets flung from a black hole's event horizon.

The team's calculations, published recently in *Physical Review Letters*, suggest that anything with gravity (meaning basically every object in the universe) will emit a Hawking-like radiation and eventually evaporate. The equations indicate that this process will take trillions on trillions of years, so it's likely that you and your personal belongings will be long gone before this effect comes into play. But the long-lived remnants of dead stars such as white dwarfs and neutron stars—which have enormous mass—might have their lives shortened if the phenomenon is real.

The analysis seems promising, says McMaken, who was not involved in the work. "This shows that there is definitively some effect where particles can be ripped apart just solely from gravitational forces in the vacuum," he adds. McMaken and his colleagues have considered doing similar calculations, he says, so he's pleased that scientists did a thorough check to see what happens in these situations.

But other researchers disagree. "Personally, I'd be kind of skeptical that all previous calculations are wrong" about what happens to particles near massive objects, says theoretical physicist Sabine Hossenfelder of the Munich Center for Mathematical Philosophy. She suspects that a more careful analysis would show that the particle-antiparticle pairs don't actually radiate from massive objects other than black holes.

Current technology isn't sensitive enough to detect this evaporative effect and prove the new claim one way or another. Falcke and his team suggest that further experiments could focus on observing the Schwinger effect, which also remains theoretical at this point, to potentially bolster their claims.

—Adam Mann

Geoff Moggridge/King's College, Cambridge

CONSERVATION

Lawn Gone

Tearing up a historic lawn brings in new bugs, bats and plants

The well-manicured lawn behind King's College Chapel at the University of Cambridge predated the American Revolution. Then, in 2019, an ecologically minded head gardener secured permission to tear up a portion of the grass and plant a meadow in its place. Before long it bloomed with poppies, buttercups and Queen Anne's lace.

Lawns, which became popular in the 1700s as displays of wealth, come at an environmental cost. They require far more water than similar-size meadows, especially in arid regions. Lawn grass is often overloaded with fertilizers and pesticides and is regularly clipped with gas-guzzling mowers. Meadows, in contrast, sequester more carbon than lawns and foster far more biodiversity.

Yet at half the size of a soccer field, how much wildlife would the new Cambridge meadow really support? King's College botanist Cicely

The King's College wildflower meadow bolstered biodiversity.

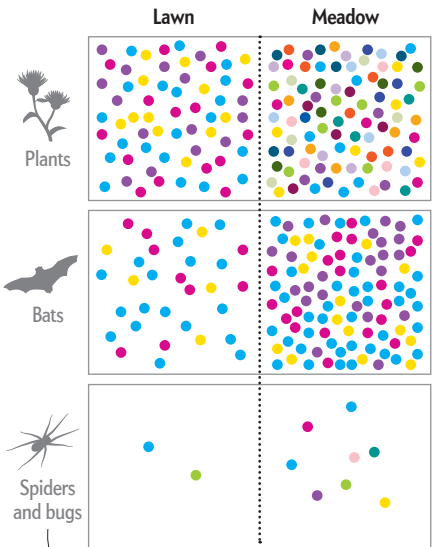
A. M. Marshall surveyed the site before and after its makeover. She and her colleagues found that, compared with their numbers in the remaining lawn, plants, bats, spiders, true bugs and other invertebrates had flourished in the meadow. And without the need for much mowing or any fertilizer, the meadow's upkeep led to 99 percent less greenhouse gas emissions per hectare than the lawn.

Perhaps because it's hemmed in by buildings and a river, no mammals were observed at the site, and it is too small for grassland birds. In addition, roundworms equally inhabited the meadow and the lawn. Even so, Marshall says she was "quite encouraged" by the results, which were recently published in *Ecological Solutions and Evidence*.

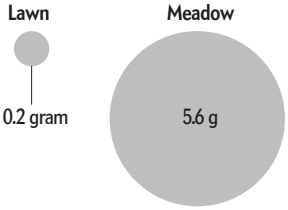
"Lawns represent an incredible loss of habitat," says Sam Quinn, a conservation biologist at the State University of New York College of Environmental Science and Forestry, who was not involved in the new study but expressed admiration for its experimental setup. Fortunately, "the restoration part is super easy," he says; once the new plants get established, "beneficial organisms" move right in. —*Jesse Greenspan*

Meadows Support More Biodiversity

Number of dots represents abundance of organisms at the Cambridge site. Color variations represent richness (number of different species).



Terrestrial invertebrates, including spiders and bugs, were also measured in terms of biomass.



Source: "Urban Wildflower Meadow Planting for Biodiversity, Climate and Society: An Evaluation at King's College, Cambridge," by Cicely A. M. Marshall et al., in *Ecological Solutions and Evidence*, Vol. 4; May 2023

Graphic by Amanda Montañez

EVOLUTION

Toxic Feathers

Two new poisonous birds have been discovered

Rufous-naped Bellbird

Martin Willis/Minden Pictures

Locals in Papua New Guinea called the birds spicy. When University of Copenhagen evolutionary ecologist Kasun Bodawatta handled feathers from the Regent Whistler and the Rufous-naped Bellbird, his eyes teared up and itched like he was chopping onions. It was the ecologist's first experience with toxic birds.

The island's toxic birds were first described scientifically in 1992, and researchers have since identified a few more species. Their feathers and skin all carry the same type of potent neurotoxin found in South American poison dart frogs. If these substances, called batrachotoxins, bind to neurons' sodium-channel proteins, they cause the neurons to fire nonstop. High-enough doses can cause muscle paralysis and death.

In a paper in *Molecular Ecology*, Bodawatta, ecologist Knud Jønsson of the Natural History Museum of Denmark and their colleagues identify two new species of toxic birds and show that each independently evolved resistance to batrachotoxins' effects via mutations that change the proteins where they bind. Like how fish and whales separately evolved fins, these birds have "arrived at the same way of dealing with" the toxins, Jønsson says.

California Academy of Sciences ornithologist Jack Dumbacher first pinned batrachotoxins as the source of birds' toxicity three decades ago. At the time batrachotoxins had been found only in poison dart frogs, half a world away. Researchers now hypothesize that the birds acquire batrachotoxins by eating poisonous beetles of the genus *Choresine,* like the frogs do—but no one is certain.

Whatever the source, storing the toxin in skin and feathers may help protect the birds against parasites, Jønsson says. Of course, for this strategy to work, the birds must avoid poisoning themselves. And just as toxins are common in biology, so is resistance to them, says University of California, Berkeley, ecologist Rebecca Tarvin.

Using computer simulations, the researchers studied how each species had evolved different variations in the neuron binding site—the same part of the protein altered in poison dart frogs—to thwart the toxin. But Tarvin isn't convinced yet. She pointed to a 2021 study in frogs in which sodium-channel mutations did not demonstrate protection from batrachotoxins in some species, although Jønsson notes that the species tested had lower than average levels of the toxins among Papua New Guinean birds. Tarvin says the new study highlights the variation among sodium channels, but there remains much to learn about toxin resistance in general.

"Understanding biodiversity and the diversity of adaptations, especially these extreme phenotypes," she says, "can give us really great ideas for medicine, for agriculture and for understanding how animals adapt to pollution." —*Carrie Arnold*

MATHEMATICS

Out of Sight

A new method for hiding secrets is mathematically proven to escape detection

In an advance that could benefit spies and dissidents alike, computer scientists have developed a way to communicate confidential information so discreetly that an adversary couldn't even know secrets were being shared. Researchers say they have created the first-ever algorithm that hides messages in realistic text, images or audio with perfect security: there is no way for an outside observer to discover a message is embedded. The scientists announced their results at the recent International Conference on Learning Representations.

The art of hiding secrets in plain sight is called steganography—distinct from the more commonly used cryptography, which hides the message itself but not the fact that it is being shared. To securely conceal their information, digital steganographers aim to embed messages in strings of words or images that are statistically identical to normal communication. Unfortunately, human-generated content is not predictable enough to achieve this perfect security. Artificial intelligence generates text and images using rules that are better defined, potentially enabling completely undetectable secret messages.

University of Oxford researcher Christian Schroeder de Witt, Carnegie Mellon University researcher Samuel Sokota and their colleagues used an AI program to create innocent-looking chat messages with secret content. To outside observers, the chat is indistinguishable from any other communication made by the same generative AI: "They might detect that there is AI-generated content," Schroeder de Witt says, "but they would not be able to tell whether you've encoded secret information into it."

To achieve this camouflage, the researchers developed an algorithm to optimally match a clandestine message with a series of memes (or text) to be sent in the chat, choosing that content on the fly to suit the context. Their big step was the way their algorithm chooses an ideal "coupling distribution" on the spot—a method that matches secret bits with innocuous content (for example, cat memes) in a way that preserves the right distributions of both while making them as interdependent as possible. This approach is computationally quite difficult, but the team incorporated recent information theory advances to find a near-optimal choice quickly. A receiver on the lookout for the message can invert the same operation to uncover the secret text.

The researchers say this technique has significant potential as humanlike generative AI becomes more commonplace. Joanna van der Merwe, privacy and protection lead at Leiden University's Learning and Innovation Center, agrees. "The use case that comes to mind is the documentation of abuses of human rights under authoritarian regimes and where the information environment is highly restricted, secretive and oppressive," van der Merwe says. The technology doesn't overcome all the challenges in such scenarios, but it's a good tool, she adds: "The more tools in the toolbox, the better." —*Dina Genkina*

PHYSICS

Flipping Out

Thanks to a viral challenge, physicists discover a new fluid dynamic effect

In experiments involving bouncy balls, plastic bottles and a high-speed camera, researchers in Chile discovered that it's possible to control the height of a container's bounce by swirling the water inside.

If this experiment sounds like something out of a social media challenge, that's because it is. Pablo Gutiérrez, a physicist studying fluid dynamics at Chile's O'Higgins University, became interested in bouncing containers after his son showed him the viral "bottle flip" challenge: tossing a half-full plastic bottle so it flips end over end and sticks the landing. "Pablo became very good at this challenge," laughs Gutiérrez's co-author Leonardo Gordillo, a physicist at the University of Santiago. "He was throwing a lot of bottles."

So the physicists and their research team took bottle flipping into the laboratory. They glued halves of rubber balls to the bottles' bottom to enhance their bounce. And they made a key observation: bottles they'd swirled before releasing bounced far less, probably thanks to fluid dynamics. To test this, the physicists built a contraption that could spin and drop bottles with scientific precision. A high-speed camera captured the drops at 2,000 frames per second. Indeed, the faster the water was swirled, the lower a bottle's bounce. The results were published in *Physical Review Letters*.

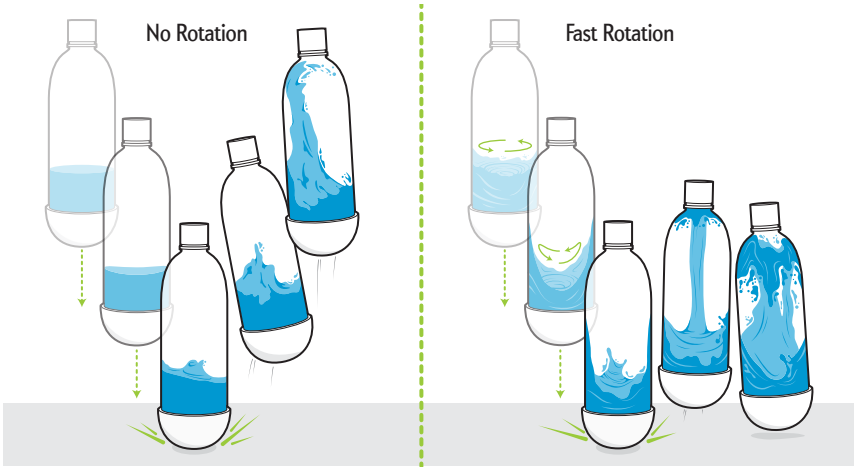
"It's true. I've tried it," says Tadd Truscott, a fluid physicist at the King Abdullah University of Science and Technology in Saudi Arabia, who was not involved in the work—but says he has tried swirling and tossing bottles by hand. "And it works quite well."

Like car passengers during a tight turn, swirling water inside a bottle gets pushed to the sides of the container, forcing it upward evenly along the walls. When the bottle hits the ground, the spun-up water courses down toward a single point at the center of the bottle's base. "All of the fluid tries to pass through [that point] but can't," Truscott says.

With nowhere else to go, the water flies back upward. Most of the falling bottle's momentum gets redirected into this vertical jet rather than into a bounce, dampening the impact and explaining why swirled bottles tend to stick their landings when "flipped." The spinning water jet then flares out like a tornado and flies apart before much of it can smack the top of a bottle and cause a delayed rebound.

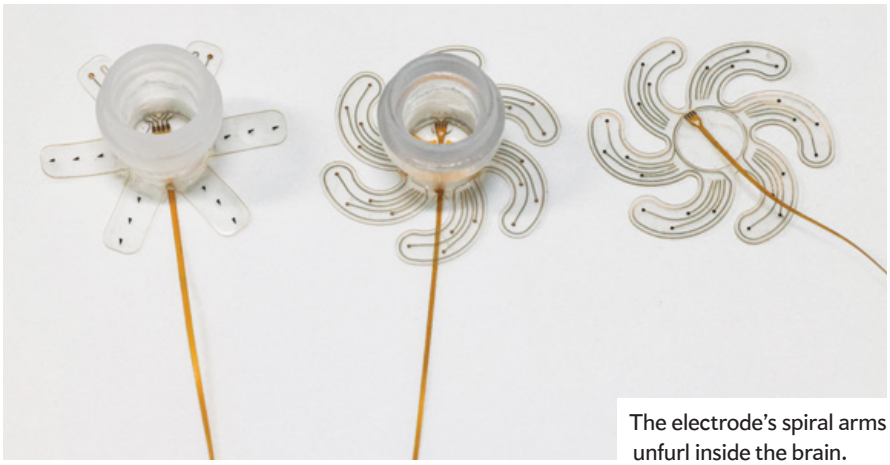
Truscott says he'd be interested to see whether the effect works for more viscous fluids or for larger container sizes. Such findings could perhaps be useful for mitigating collision damage to fluid-filled containers like fuel tanks. It could also make for an afternoon of fun at home; the researchers encourage readers to give a bottle a swirl and replicate the results for themselves.

—Elise Cutts



Source: "Swirling Fluid Reduces the Bounce of Partially Filled Containers," by Klebbert Andrade et al., in *Physical Review Letters*, Vol. 130: June 16, 2023

Graphic by Brown Bird Design



The electrode's spiral arms unfurl inside the brain.

Alain Herzog/EPFL 2023

TECH

Head Space

A flexible robot electrode deploys inside the skull

Scientists have made great strides in developing soft "biocompatible" electrodes. But comparatively less attention has gone toward how to actually get these devices—which have wide applications in brain-machine interfaces, such as for controlling prosthetic devices—inside people's heads. Researchers led by Stéphanie Lacour, a neurotechnologist at Switzerland's Ecole Polytechnique Fédérale de Lausanne (EPFL), presented an ingenious solution to this problem in *Science Robotics*.

Electrode arrays that sit on the brain's surface are most often used to map seizure-related brain activity in people with epilepsy. This technique requires arrays that cover relatively large areas, necessitating removal of at least an equal area of skull in a procedure known as a craniotomy.

The implant Lacour and her colleagues built is instead inserted through a much smaller hole in the skull. "It really solves a major, long-standing practical problem … with a solution simple enough it seems realistic to translate to the clinic," says Chalmers University of Technology bioengineer Maria Asplund, who was not involved in the study but wrote an accompanying commentary.

The implant is made of a stretchable "elastomer" material that mimics the dura, the membrane surrounding the brain. The study's lead author, Sukho Song, an engineer also at EPFL, borrowed a technique called eversion from soft robotics to add a novel deployment mechanism: Initially the electrode array's "arms" are tucked inside a cylindrical loader like the fingers of an inverted glove. Once the loader is inserted in the small hole, fluid pressure drives each arm to extend horizontally in the one-millimeter space between the skull and the brain. A strain sensor signals full extension.

The team used a physical brain-and-skull model to work out the best shapes and dimensions to maximize coverage while minimizing tissue compression. The current prototype fits through a two-centimeter hole and extends six spiral-shaped arms, enabling even coverage of a four-centimeter-diameter area.

The most similar previous effort, built for the spinal cord, would take up too much space if used in the brain. "What's added here is that the implant makes only the movement you'd like it to," Asplund says. "It should have minimal volume and expand only in one plane."

The researchers tested the technique by implanting a simpler device with one straight arm in a miniature pig. They positioned it over the somatosensory cortex, which processes touch, and confirmed that appropriate signals registered when the animal's snout was stimulated. They saw no visible signs of brain damage afterward, although microscopic investigation revealed a very slight immune reaction. "This has to be pursued further," Lacour says, "but these are encouraging first steps."

A spinoff company, Neurosoft Bioelectronics, is working on clinical applications. "They're making good progress toward medical-grade fabrication," Lacour says. "And they're in discussion with regulatory bodies."

—Simon Makin

ARTIFICIAL INTELLIGENCE

Flop or Bop?

Researchers are using AI to try to predict hit songs

Can a machine predict the song of the summer? Can it weed out forgettable flops? If so, such a technology could reduce music production costs, curate public playlists and even render judges on television talent shows obsolete—but after decades of "hit song science" research, predicting a successful song is still more of an art than a science.

Now researchers at Claremont Graduate University in California say they've found a way to use artificial intelligence to analyze listeners' physiological signals and predict the next chart-topping bop. The team tracked participants' heart activity as they listened to music. The scientists used an algorithm to convert the data into what they say is a proxy for neural activity. A machine-learning model trained on the data was then able to determine whether a song was a hit or a flop with 97 percent accuracy. The findings were published in *Frontiers in Artificial Intelligence*.

Other scientists studying the use of AI to predict hit songs aren't ready to declare victory yet. "The study could be groundbreaking but only if it's replicated and generalizable. There are many biases that can influence a machine-learning experiment, especially one that attempts to predict human preferences," says Hoda Khalil, a data scientist at Carleton University in Ontario, who was not affiliated with the study.

Traditionally, music industry experts looking to predict the next hit have relied on large databases to analyze the lyrical and acoustic aspects of hit songs, such as tempo, explicitness and danceability. But this method has performed only slightly better than a random coin toss. For example, Khalil and her colleagues have analyzed data from more than 600,000 songs and found no significant corre-

lations between various acoustic features and a tune's commercial popularity.

Rather than focusing on a song's qualities, the Claremont team sought to explore how humans respond to music. "The connection seemed almost too simple. Songs are designed to create an emotional experience for people, and those emotions come from the brain," says Paul Zak, a neuroeconomist at Claremont Graduate University and senior author of the new study.

Previous attempts to use brain scans to predict hit songs had limited success. A 2011 study using functional magnetic resonance imaging, which tracks blood flow in the brain, identified 90 percent of commercial flops but only 30 percent of hits. Zak's team took a different approach. Instead of directly measuring brain responses, the researchers equipped 33 participants with wearable cardiac sensors that monitor changes in blood flow, similar to the way traditional smartwatches and fitness trackers detect heart rate.

Participants listened to 24 songs ranging from the megahit "Dance Monkey" by Tones and I to the commercial flop "Dekario (Pain)" by NLE Choppa. Their cardiac data were then fed through the commercial platform Immersion Neuroscience, co-founded by Zak, which he says algorithmically converts cardiac activity into a combined metric of attention and emotional resonance known as immersion (the details of this process are not outlined in the study). An AI model trained on these immersion signals predicted hit songs with high accuracy, the researchers reported. In contrast, participants' ranking of how much they enjoyed a song did not reflect its public popularity.

Zak—who currently serves as Immersion Neuroscience's chief immersion officer—says there is a rationale for using cardiac data, which can be easily tracked through wearable devices, as a proxy for neural response. He explains that a robust emotional response triggers the brain to synthesize the "feel-good" neurochemical oxytocin, intensifying activity in the vagus nerve, which connects the brain, gut and heart.

Not everyone is convinced. "The study hinges on the neurophysiological measure of immersion, but this measure needs further scientific validation," says Stefan Koelsch, a neuroscientist at the University of

miniseries/Getty Images

Bergen in Norway and guest researcher at the Max Planck Institute for Human Cognitive and Brain Sciences in Germany. Koelsch also notes that although the study cited several papers to support the validity of immersion as a measure of brain activity, not all were published in peer-reviewed journals.

Koelsch is also skeptical that machine-learning models can capture the nuances that make a song a hit. In a 2019 study, he and his colleagues initially found a relation between the predictability of a song's chord progression and listeners' emotional response, but they have since been unable to replicate those findings. "It's very difficult to find reliable indicators for even the crudest differences between pleasant and unpleasant music, let alone for the subtle differences that make a nice musical piece become a hit," he says. As of publication time, Zak had not responded to requests for comment on criticisms of his recent study.

If this new model's results are replicated, it might hold immense commercial potential. To Zak, its primary utility lies in efficiently sorting through the vast library of existing songs. "As wearable devices become cheaper and more common, this technology can passively monitor your brain activity and recommend music, movies or TV shows based on those data," Zak says. "Who wouldn't want that?"

Zak envisions an opt-in service with data anonymized and shared when users sign a consent form. But Khalil points out that this opt-in approach can still fail to safeguard users. "Many users just accept the terms and conditions without even reading them," Khalil says. "That opens the door for data to be unintentionally shared and abused."

One's favorite songs may seem like innocuous data, but they offer a window into one's moods and habits. And if these details are coupled with data on brain activity, consumers may be forced to consider how much information they're willing to relinquish for the perfect playlist. —*Lucy Tu*

BIODIVERSITY

Science in Images

By Allison Parshall

Deep in eastern Brazil's Atlantic Forest, a team of biologists spotted a fuzzy purple stalk protruding from the leaf litter on the ground. Following the spore-covered body down into the soil, they found a mummified spider swaddled in fungal filaments called hyphae.

One of the mycologists, João Araújo, immediately recognized the purple protrusion as a new, undocumented species of predatory fungus belonging to the genus *Purpureocillium*. Spores from these fungi latch onto and kill their insect or arachnid prey—and then a fruiting body bursts from the corpse to spread more spores.

Purpureocillium species share many similarities with those of their sister genus *Ophiocordyceps*, which includes the "zombifying" fungi that hijack the bodies of their insect prey and are featured in the apocalyptic television show and video game *The Last of Us*. Araújo, who works for the New York Botanical Garden, has dedicated his career to discovering new species in this intriguing evolutionary group. "Many of these specimens we collect are new species," he says. "We know so little about them."

The "beautiful, velvety" purple specimen would be only the seventh species of *Purpureocillium* discovered, says Jennifer Luangsa-ard, a mycologist at Thailand's National Center for Genetic Engineering and Biotechnology. These fungi are found across the world and include one species that causes eye and skin infections in immunocompromised people. Scientists know surprisingly little about the fungal kingdom despite its importance for our health, food and environment; according to conservative estimates, only 10 percent of species have been identified, Luangsa-ard says. "We need more people looking for the missing taxa," she adds. There's "still a lot to be discovered."

The wild popularity of *The Last of Us* may lead people to spot new species, which are often hiding in plain sight, Araújo says. He adds that a naturalist recently spotted two potential species of *Ophiocordyceps* infecting ants at a nature preserve in Pennsylvania, a short drive from Araújo's laboratory. This discovery may allow his team to closely study the still mysterious ways these fungi manipulate and kill their prey.

To see more, visit ScientificAmerican.com/science-in-images

João Araújo

MEDICINE

Stopping Time

Nanoparticles allow long-term freezing of transplant organs

Thousands of donated organs are discarded every year. As soon as one becomes available, doctors race to find a compatible recipient—but transplantation time lines are measured in hours, and many organs still can't be used. Now researchers publishing in *Nature Communications* have successfully preserved rat kidneys for 100 days before thawing and transplanting them into other rats.

Scientists have cryogenically preserved organs for decades via vitrification: cooling them so quickly that ice cannot form and rupture cells. But thawing them quickly enough to avoid damage has proved nearly impossible. "If the outside heats faster than the middle, you get thermal stress—like when you drop an ice cube in water and you hear it crack," says study author Erik Finger, a transplant surgeon at the University of Minnesota. "You could basically put a crack right through the middle of the organ and make it not function."

For the new study, just before vitrification the team flooded the rat kidneys' vasculature with iron oxide nanoparticles and a newly developed cryoprotective solution that can preserve the organs at extremely low temperatures. After 100 days, they thawed the organs with an alternating magnetic field, which caused the nanoparticles to oscillate and evenly warm the tissue. The researchers then flushed the nanoparticles and cryoprotective solution out of the organs before replacing the rats' native kidneys with these transplants. The recipients were able to live without medical support.

Only one previous study successfully rewarmed and transplanted a vitrified organ in any animal, and the rabbit kidney in question had been vitrified for roughly 10 minutes—and it performed poorly after transplantation. Drastically extending the preservation period and developing a new method for warming was a "crowning achievement" for the researchers, says Gloria Elliott, president and chief science officer for the Organ Preservation Alliance. "No one has been able to do a good job of reproducing that," Elliott adds. "So it's been a long time coming."

Human organs are bigger than rat organs, but Finger is optimistic this technology will translate because of how the nanoparticles uniformly heat an organ from within. New York University surgery resident David Andrijevic, who revived dead pigs' organs while working as a research scientist at Yale University, says this study completely changes the field of transplantation. He adds that "100 days is absurdly long."

Finger's group hopes to start human organ trials within the next six months. Scaling up will be a challenge, Finger says, but long-term organ banking would be invaluable for the 100,000 people on the organ transplant waiting list. "For each organ recipient who does not know when the transplant might come," he says, "you can say, 'What's in the freezer?' and pick out what's best for this particular patient today."

—Timmy Broderick

Illustration by Thomas Fuchs

BIOLOGY

In the Depths

The world's deepest-dwelling fish thrives five miles down

Scientists exploring a marine trench near Japan were astonished to see a fish in one of the deepest parts of the ocean, at 8,336 meters (about five miles) below the surface. The tadpole-shaped, translucent snailfish is probably living at the greatest depth possible.

"They can't really go any deeper," says marine scientist Alan Jamieson of the University of Western Australia, who led the team that made the discovery. The previous record holder, a snailfish seen in the Mariana Trench—the world's deepest location—was filmed 8,178 meters under the surface in 2017.

Fish can tolerate high pressures at extreme depths because of cellular compounds called osmolytes. Osmolyte concentrations increase at greater depths to ensure that fish cells can withstand such bone-crushing pressures, but these compounds reach their maximum concentration at around 8,400 meters. So that's the theoretical limit of fish physiology. "If anyone does find fish deeper than this, it will not be by much," Jamieson says.

Ichthyologist Prosanta Chakrabarty, curator of fishes at Louisiana State University's Museum of Natural Science, is impressed that the fish could survive at 800 times the surface's water pressure. "At that depth everything from gas exchange for breathing to nearly every physiological function seems impossible," he says. "I can barely swim to the bottom of a swimming pool without my ears popping."

Jamieson's team discovered the snailfish in August 2022 at the bottom of the Izu-Ogasawara Trench, near the main islands of Japan. The farthest depths of the Japanese trench reach about 1.7 degrees Celsius (35 degrees Fahrenheit), Jamieson says, which is slightly warmer than the neighboring Mariana. This divergence is key: osmolytes are less effective at low temperatures, and these snailfish live near the edge of what's possible. "The difference is a fraction of a degree, so we wouldn't care," Jamieson says. "But it makes a difference to marine animals."

To photograph the fish, researchers onboard the DSSV *Pressure Drop* sent down an autonomous underwater "lander" equipped with cameras, lights and batteries, along with a weight to lower the contraption to the seafloor. The lander carried dead fish as bait to lure deep-sea crustaceans, and the snailfish came to eat the crustaceans—including the record-breaking juvenile snailfish at 8,336 meters. Although the team couldn't identify its exact species, two others from the species *Pseudoliparis belyaevi* were caught in baited traps nearby, at a depth of 8,022 meters.

Each of the more than 400 known snailfish species adapts to where it lives, from shallow waters to extreme depths, Jamieson says. "Each trench has its own snailfish in it," he says. "Once they've evolved to cope in a trench, they cannot decompress to get from one trench to another." —*Tom Metcalfe*

University of Western Australia

This snailfish lives at nearly impossible depths.

NEWS AROUND THE WORLD

Quick Hits

By Timmy Broderick

ICELAND

Iceland's government temporarily halted fin whale hunting after the country's veterinary authority released a gruesome whale hunt video. Public opposition has increased in recent years, and experts say the ban could become permanent.

INDONESIA

Scientists recorded wild orangutans producing both voiced and voiceless vocal patterns—a feat previously attributed mostly to songbirds and human beatboxers. Orangutans use two sounds at the same time before combat and as a warning to others of potential threats.

ISRAEL

Archaeologists examined sediment in 2,700-year-old toilets in Jerusalem and found the oldest known traces of *Giardia duodenalis*, a pathogen that can cause the intestinal malady dysentery. Ancient texts hint at its existence, but these feces predate most other evidence by hundreds of years.

PERU

People have been preparing for El Niño's floods for centuries. New research found millennia-old flood sediments in northern Peru that suggest ancient communities were aware of the intermittent weather pattern's dangers and built walls to protect farmland.

TONGA

Hunga Tonga-Hunga Ha'apai's volcanic blast last year was the most powerful such event ever recorded in the modern era. Now scientists have released data showing that the subsequent ash plume also broke another record: the most extreme lightning storm known, with 192,000 flashes over 11 hours.

U.K.

In urban landscapes, pollinating moths may be as important as bees. Researchers found that these insects carry more diverse pollen than bees do and visit just as many plants during parts of the summer—but scientists worry they may be even more vulnerable to urbanization.

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Water Striders

Little single scullers striding
on the surface tension of the pond
glide by the turtle-paved bank,
can't sink to the muddy bottom.
Their narrow bodies and thready legs
look like racers' shells and oars.
They criss and cross their skim of water.
I doubt they ponder what's above or under.
The regatta of the striders' lives
looks merry though death will come
by frog or cold or generation's close.
Best not to dive too deep
into that question but stay amazed
at the forces that let them float
and row with greater ease
than the human sculler in a boat.

Lynn Levin teaches writing and literature at Drexel University. Her 2023 debut collection of short stories, *House Parties* (Spuyten Duyvil), follows her numerous books of poetry, among them *The Minor Virtues* (2020) and *Miss Plastique* (2013), both published by Ragged Sky Press.

Fallowing

I cosseted my weary garden with clover,
practiced patience, saw the vanity of overwork.
The plants fixed nitrogen in the dark
and new riches formed under the green cover.

The land's sabbatical is not unlike human sleep
when the dark dome drops over the aviary of the mind
and the brain consolidates its record of time
through mysterious processes in slow-wave sleep

inscribing in cells what one has skimmed
from the hours: joy and sorrow, anxiety, relief.
That year of fallowing felt brief
but not as brief as the days that spin

or the busy nights that fix in the mind
precious faces, conversations, names,
the memories one wishes to keep safe
though some be rooted in places hard to find.

Phil Degginger/Alamy Stock Photo

Lydia Denworth is an award-winning science journalist and contributing editor for *Scientific American*. She is author of *Friendship: The Evolution, Biology, and Extraordinary Power of Life's Fundamental Bond* (W. W. Norton, 2020) and several other books of popular science.

Hearing Aids May Lower Risk of Dementia

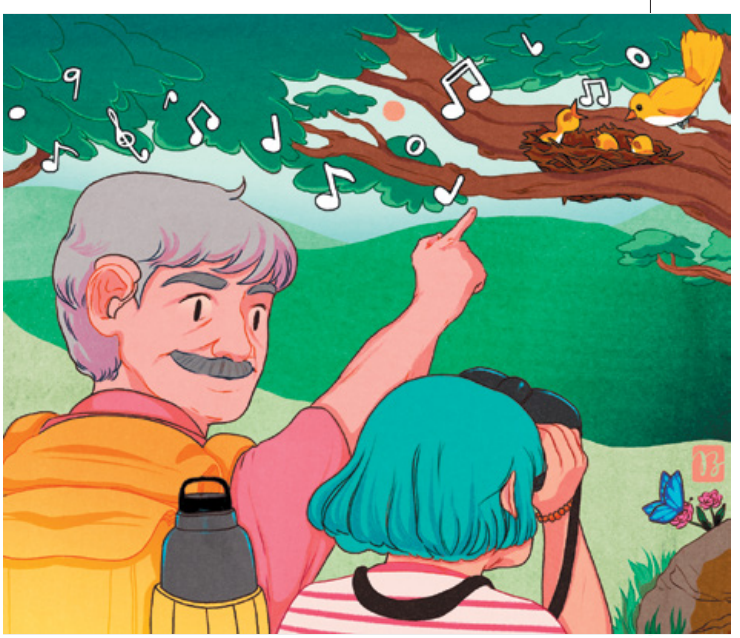
Age-related hearing loss is linked to mental and physical problems

By Lydia Denworth

A friend recently noticed that she couldn't always hear her phone ringing or family members calling from another room. A hearing test revealed mild loss in high frequencies, which was possibly age-related—she is in her early 60s, and some difficulty with these frequencies often comes with advancing years. She didn't need hearing aids yet, but she says she'll monitor the situation and get them if the time comes. She was glad she asked for the test.

Not many people do, nor do most doctors offer. It's not routine to screen adults for hearing loss even though about 14 percent of Americans older than 12 have trouble hearing. The prevalence increases dramatically with age, to half or more of those over 70. Hearing loss often comes on so gradually that many don't notice; others ignore it. Only an estimated 15 to 25 percent of adults who would benefit from hearing aids use them, and use is lowest among people who have less access to health care.

Yet recent research has revealed that even mild or moderate hearing loss in older adults is associated with accelerated cognitive decline. People with hearing loss are more likely to develop dementia, and the likelihood increases with the severity of the loss. In 2020 a Lancet Commission on dementia identified hearing loss as the leading modifiable midlife risk factor for later development of the disease.



In July, at the annual meeting of the Alzheimer's Association, Frank Lin, an otolaryngologist and director of the Cochlear Center for Hearing and Public Health at Johns Hopkins University, presented results from a first-of-its-kind randomized clinical trial of 977 adults between 70 and 84 with untreated hearing loss. One group received best-practice hearing care, including aids, and another group took part in a program about successful aging. Three years later hearing aids did not make much difference to the healthiest participants. But those who were at the higher risk for dementia because of age and underlying health conditions saw a 48 percent reduction in cognitive change if they got hearing aids.

When hearing loss is untreated, the brain's organization changes, says auditory neuroscientist Anu Sharma of the University of Colorado Boulder. In adults with mild hearing loss, studies show a decrease in gray matter. Sharma found early signs that vision and touch areas of the brain encroach on and repurpose underused hearing areas. Adults with hearing loss also show more activity in working memory areas; they need to make extra efforts just to listen, Sharma says, which may deplete cognitive reserves.

Hearing loss is also associated with more falls, higher healthcare costs, and increased loneliness and social isolation. "Hearing is fundamental to healthy aging," says Nicholas Reed, an audiologist and epidemiologist at Johns Hopkins, who worked with Lin on the cognitive-decline study.

These consequences of hearing loss contributed to the Food and Drug Administration's decision last year to create a category of over-the-counter hearing aids. Traditional aids, dispensed by audiologists, average $4,700 a pair and are not covered by Medicare or most private insurance. Most of the new OTC devices cost between $500 and $1,900. But quality varies a lot in this range. The high end includes customizable devices. Less expensive aids are preset with limited options—a one-size-fits-all approach that doesn't really fit all.

Most users of OTC devices still benefit from help getting set up and then troubleshooting devices. But set-up help doesn't have to come from audiologists. In Baltimore, the Johns Hopkins Cochlear Center created a successful program of peer mentoring for older low-income adults with hearing loss.

It's too soon to assess whether the new devices will close the yawning gap between the large need for hearing aids and the smaller demand for them. In one survey, only about half of nonusers said they would use hearing aids even if they were free. It may help that popular consumer-oriented brands such as Hewlett-Packard and Jabra have jumped into the field. The key to getting around stigma will be "the ubiquity of wanting to hear well" and the sense that "everyone is doing it," Lin says. If "wireless earbuds also become hearing aids, that changes the whole perspective of what it means to use hearing technology." SA

Illustration by Jay Bendt

Puritanical Law Strikes Again

The Comstock Act against "obscene" material has legal influence today

By Tanya Lewis

A high-stakes case involving access to the abortion pill mifepristone has been wending its way through the courts this year. At issue is the U.S. Food and Drug Administration's approval of the drug, one of two medications that have been prescribed together for more than two decades to end pregnancies.

In early April, Texas district judge Matthew Kacsmaryk ruled in favor of antiabortion organizations and doctors demanding the FDA's approval of mifepristone be revoked. The Fifth Circuit Court of Appeals issued a partial stay of the ruling, maintaining mifepristone's approval but restricting its distribution. The U.S. Supreme Court temporarily preserved access to the drug while the case is being heard by the Fifth Circuit Court. As of this writing, the appeals court had not issued a ruling, but the case is most likely headed back to the Supreme Court.

Kacsmaryk's ruling and the initial Fifth Circuit decision cited a 19th-century law known as the Comstock Act of 1873, which made it illegal to send "obscene, lewd or lascivious" materials by mail—including information related to abortion or contraception. Although the Supreme Court greatly weakened the law in the 1960s, it quietly remained on the books until the mifepristone lawsuit revived it.

Science journalist and author Annalee Newitz spent years interviewing people about the Comstock Act and researching Comstock himself for their 2019 novel *The Future of Another Timeline*, in which characters time travel to try to block the original antiobscenity crusade. SCIENTIFIC AMERICAN spoke with Newitz about how this 150-year-old law is still being used to restrict reproductive rights.

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

Tell me about Anthony Comstock, for whom this law is named.

He was a very famous moral crusader based in New York [City] in the mid-19th century. Comstock was interested in stamping out obscenity—and by "obscenity," he meant any imagery or literature that contained nudity, among other things. He was ex-

Illustration by Shideh Ghandeharizadeh

Tanya Lewis is a senior editor covering health and medicine for *Scientific American*.

treme for his time, but at a certain point he managed to connect with the New York City YMCA, which was also against what it was referring to as obscenity. By connecting with that organization, he got access to a lot of powerful New Yorkers who were able to fund his campaign. He got himself a position as a special inspector at the postal service. Much of the Comstock Act's power comes from the ability to regulate communications across state lines.

The law forbids the sending of obscene materials through the mail. Comstock was enforcing the law by ordering tons of items through the mail, from contraceptives and sex toys to erotic images and abortifacients [substances that end a pregnancy]. Then, after receiving the items, he would prosecute the people sending them. He was targeting people who were known to be selling the raw material but also, more important, people who were selling any kind of information that was [sex] education-related—literally things like "here's how to make a baby" and information about birth control and abortion. The Comstock Act was actually a First Amendment exemption law. It was a law about what could be said and what could be passed through the mail. Any information or material related to reproductive health or abortion or sex education was classified as obscene.

In the early 20th century playwright George Bernard Shaw wrote an op-ed in the *New York Times* making fun of Comstock—because by the late 19th century, even though the laws were in effect, many modern young people thought he was an idiot. Shaw said America was suffering from "Comstockery." He was using this term to refer to the censorship and puritanical nature of American art, and it became a meme. People started using "Comstockery" to make fun of any kind of art or storytelling or writing or politics that was old-fashioned and puritanical.

How have the Comstock Act and related laws evolved over time?

The Comstock laws were being actively used basically through the 1960s, which is shocking. And in the 1970s we saw on the Supreme Court a revolution in our understanding of what obscenity is and a kind of rejiggering of the First Amendment—because, remember, obscenity is an exemption to the First Amendment.

In the early 20th century this idea of Comstockery became very popular. The laws were viewed as old-fashioned, and they weren't really taken off the books, but they were mostly ignored. And at the same time, courts were using them to continue limiting, especially, abortifacients, abortion information and reproductive health information.

In the 1930s there were some rulings around the Comstock Act that broadened its application to different kinds of birth control but at the same time limited how the law could be used if people were sending abortifacients for unlawful uses. So in the 1930s there's this limit where it counts under the Comstock Act only if you deliberately are sending somebody something to illegally abort a pregnancy. Then, in the 1950s, there was an expansion of the Comstock Act to include any substance that could lead to an abortion.

Then you get this shift in the early 1970s around privacy law, and reproductive health is placed under privacy. Pretty much every lawyer I've ever talked to about this who's superknowledgeable about reproductive rights is like, Why did we do that? That was such a precarious ruling—so easy to roll back, as we've seen with last year's Supreme Court decision overturning *Roe v. Wade*. But it seemed like a good idea at the time. In the process, of course, that meant these Comstock laws remained on the books in many places.

In *The Future of Another Timeline*, characters travel back in time to try to prevent the Comstock laws. When you wrote the book, did you expect these laws to be used in a ruling like that in the recent mifepristone case?

Definitely not. I'm probably the only person who has written a time-travel story about trying to defeat Comstock, although I'd love to be wrong about that. But there are a lot of law experts and obscenity experts whose work I've read over the years who have said the laws that protect people's rights to have an abortion and to have access to birth control are superprecarious—and what we need is a law that says abortion is legal and birth control is legal. But what we keep doing because of our Comstockery as a nation is saying, "Oh, we wouldn't want to give people rights to have an abortion. Why don't we just say that they have a right to do whatever they want in private, and then we'll just avoid talking about the issue?" And what that means is that we continue to allow women to be [treated like] second-class citizens.

How did Comstock use the courts and other means to enforce his agenda?

In the 19th century Comstock was like, "I'm going to use surveillance, and I'll use this brand-new position in the postal service to police what I call obscenity." He also ran this organization called the New York Society for the Suppression of Vice, which just sounds like something out of a Marvel comic. And they would do these arrests all the time. So it feels very much like, yes, it comes out of using the courts. But it also comes out of abusing police power because these were people who were, like, pseudo police officers, and they would figure out who was an abortion provider.

It's all tied up with a lot of the same issues that we're grappling with nowadays: What kinds of books should we allow children to read? What should police powers be? What is the role of courts? But now that they're picking on mifepristone, I think we're going to get a really funny backlash from an unexpected source perhaps—which is the pharmaceutical industry. I think the pharmaceutical industry is saying, "This is going to go after our bottom line."

What happened to Comstock himself?

He was basically laughed out of his positions of power. By the time he died, he was considered to be just a joke. Right after he died is when Margaret Sanger started founding her clinics, which eventually became Planned Parenthood. So even that aspect of his work was kind of crushed under the wheels of this new era of family planning. SA

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NEXT-GEN CRISPR AND THE FUTURE OF **GENE EDITING**

Known for co-inventing CRISPR, Emmanuelle Charpentier discusses how advances in gene editing could transform agriculture, medicine and science itself

The practice of genetic modification is as old as humanity. For thousands of years, humans have bred crops, livestock and even pets that possess desirable traits. This selective process, which alters an offspring's genome, began long before anyone knew of genes or DNA, and it has shaped the course of human civilization.

The same might one day be said for the gene-editing technology known as CRISPR (clustered regularly interspaced short palindromic repeats). In a decade, scientists have transformed CRISPR from a natural system used by bacteria to block viral attacks into a molecular scalpel for genetic engineering. CRISPR permits researchers to make precise deletions or substitutions in a specific genetic sequence. Its applications have proliferated, and already many have begun to transform approaches to agriculture and disease research and treatment.

As a chief architect of formative CRISPR research, Emmanuelle Charpentier shared the 2018 Kavli Prize in Nanoscience with Jennifer Doudna and Virginijus Šikšnys—followed by a 2020 Nobel prize with Doudna.

Charpentier talked with Scientific American Custom Media about how to harness the full power of CRISPR to fortify crops against the impacts of climate change; how to accelerate the treatment of infectious and genetic diseases; and what lies ahead for science itself.

Will we be able to use CRISPR as a drug to treat human disease?

There is great interest in this. Right now, CRISPR is being developed to treat certain blood disorders like sickle cell disease. In that case, hematopoietic stem cells are harvested from the patient, and the disease-related gene is edited with CRISPR outside the body, before the cells are given back to the patient. These cell-based therapies are awaiting approval from the FDA and European regulators, and the first patients are expected to receive treatment with the commercial version in the coming year.

For disorders caused by single genetic mutations, like Huntington's disease and certain forms of Alzheimer's disease, the delivery of CRISPR-Cas9 to tissues inside the body is a bottleneck. A delivery system has to be safe, with no secondary effects. It also needs to be precise enough to target a specific tissue and provide the

correct amount of CRISPR-Cas9 to cells. People are working to develop delivery systems, such as lipid nanoparticles and lentiviral vectors, but it remains a key challenge.

Could CRISPR be used to combat infectious disease?

Some biotech companies are developing strategies that use CRISPR to target the DNA of certain bacterial species. The idea is that DNA repair mechanisms in bacteria are relatively weak, so DNA cleaved by CRISPR-Cas9 would not be repaired or fully replicated, and the bacteria would not survive. This approach looks nice on paper, but there are a few hurdles to treating bacterial infections, including how to bring CRISPR to the right bacterial species in the body. I do think CRISPR could be a promising way to treat viruses like HIV. Researchers could modify the CCR5 receptor that HIV uses to enter immune cells. This approach would not prevent infection, but it would block viral propagation.

How can CRISPR be used to improve agriculture?

CRISPR offers the possibility of engineering plant crops that will help us face the challenges of climate change. One approach is to challenge plants with the types of stresses we think will be encountered in the future, such as rising temperatures and drought. Researchers then sequence the genomes of the plants that can resist those stresses and identify the mutations that confer resistance. They can then use CRISPR to reproduce the mutation that allows a plant crop to resist such challenges. CRISPR could also be used to custom-design plants optimized for a farmer's soil type—a kind of personalized agriculture. The challenges of climate change are coming faster than we can react to them. If we don't apply these technologies, there will be a part of the world without enough food.

How can we ensure that the scientific enterprise remains vibrant in the future?

Since the pandemic, a lot of PhD students have skipped a postdoc to go directly into startups and biotechs. Biotechs can be innovative, but we have to make sure that basic research is sustained. In the past, at least in Europe, labs were given core funding to do research without the need to constantly write grants. This model could provide some balance. Also, I think a lot of young researchers don't want the pressure of being a group leader, so they go to a company where they can be part of a team. Maybe public institutions should evolve to be more like companies, with smaller groups that work together in an environment where everyone is supported, and success is evaluated at the level of the institute and its projects, not the individual.

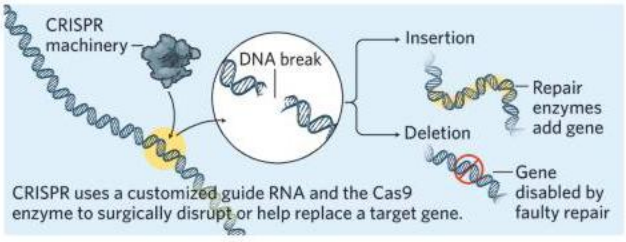
Could microbes harbor other mechanisms that we could exploit technologically?

Bacteria are in a constant war with viruses. To survive, they have evolved novel defense systems. CRISPR-Cas9 is one of those, but we continue to discover others on a regular basis. The technologies we use in molecular biology and genetics have primarily come from basic research performed on microorganisms, and often on bacterial defense systems. Nature has a lot to offer and much of it is likely better than anything we could imagine.

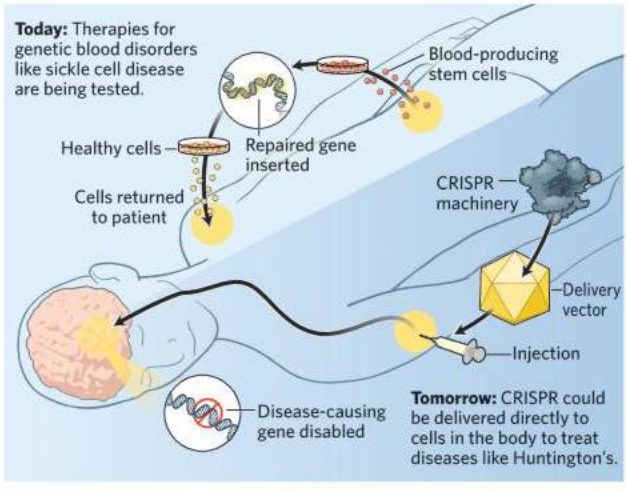
To learn more about the work of Kavli Prize Laureates, visit kavliprize.org.

REWRITING THE GENETIC FUTURE

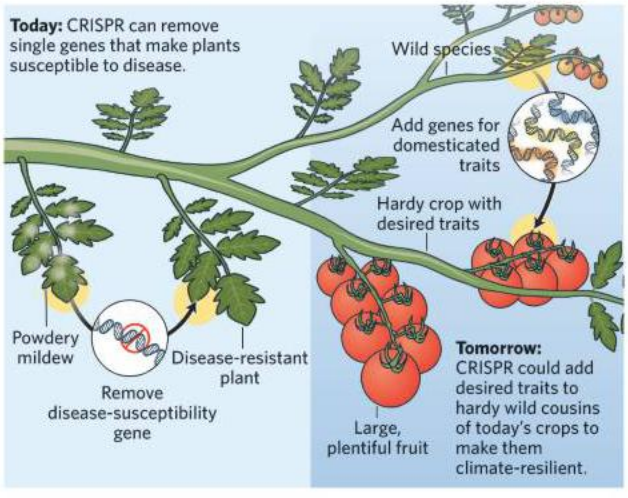
CRISPR can edit genes with unprecedented precision, transforming the way we treat disease and breed fortified crops



CRISPR in Medicine



CRISPR in Agriculture



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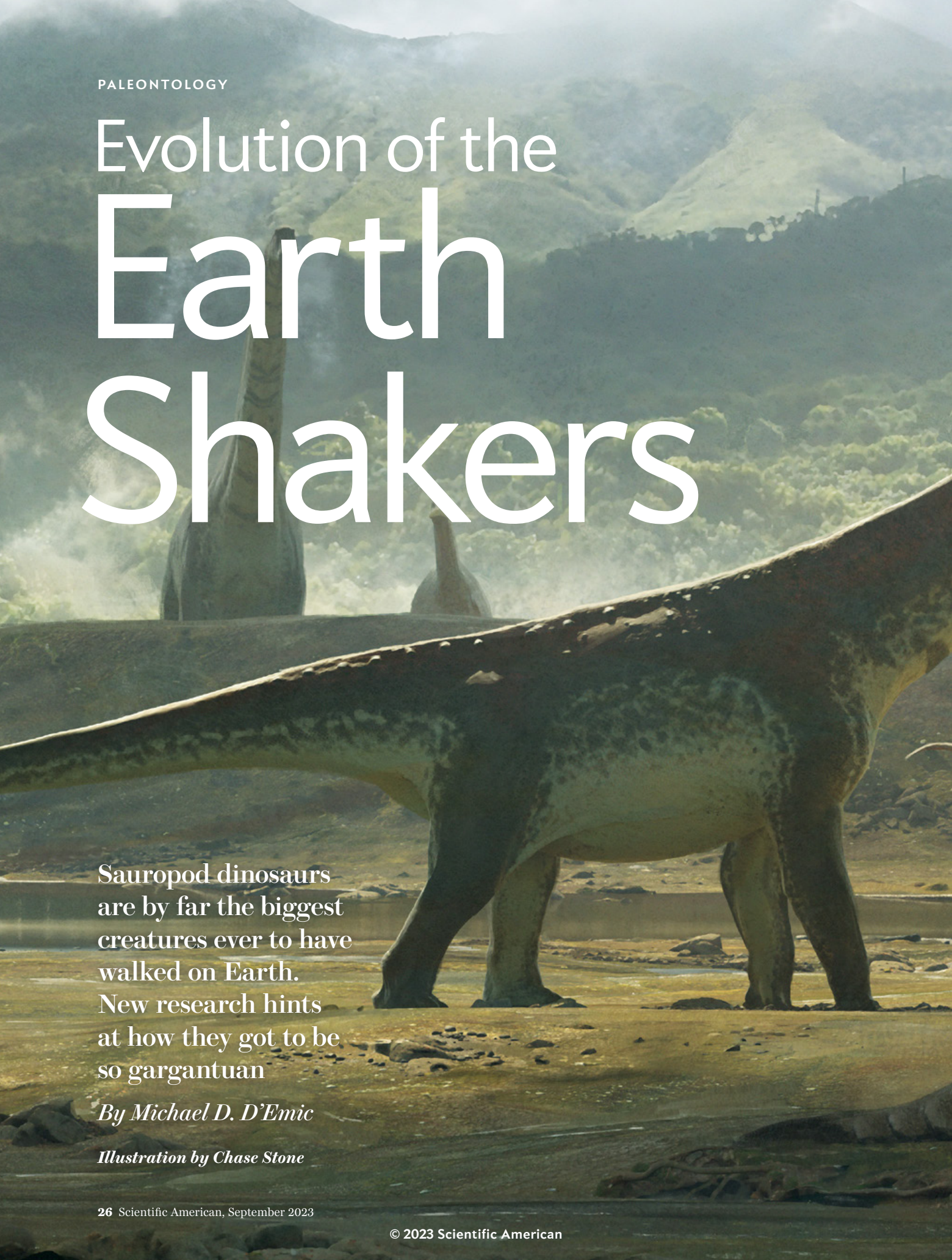


Sauropod dinosaurs are by far the biggest creatures ever to have walked on Earth. New research hints at how they got to be so gargantuan

By Michael D. D'Emic

Illustration by Chase Stone

SAUROPOD DINOSAURS such as *Argentinosaurus* evolved larger body sizes than any other group of terrestrial animals.

Michael D. D'Emic is a paleontologist at Adelphi University. He studies the evolution of growth and body size in dinosaurs.

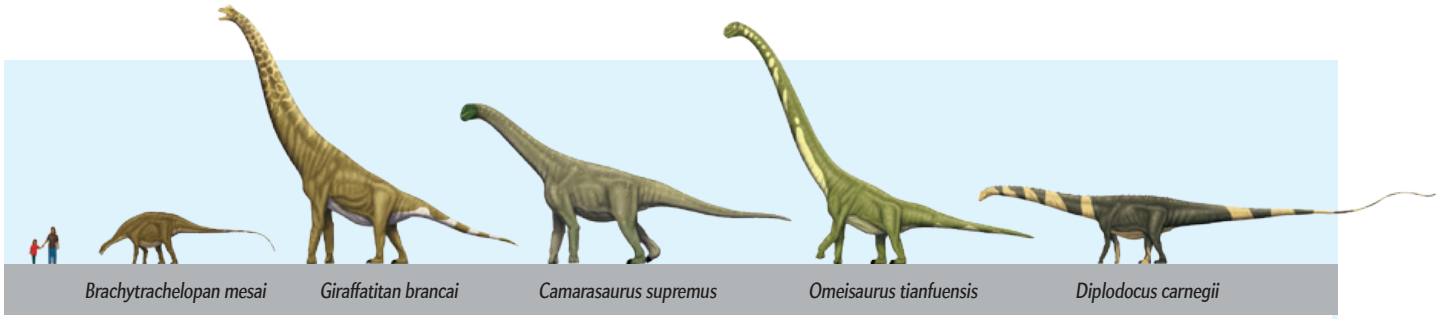
OF ALL THE ANIMALS EVER TO HAVE ROAMED THE PLANET, THE ICONIC long-necked, long-tailed dinosaurs known as sauropods stand unrivaled. No other terrestrial creatures have come close to attaining their colossal sizes. They overshadowed all other dinosaurs, from the duck-billed hadrosaurs and the horned ceratopsians to the armored ankylosaurs and predatory tyrannosaurs. Even the mightiest land mammals—mammoths and rhinoceroslike beasts that were up to twice as heavy as the largest elephants alive today—were featherweights compared with the biggest sauropods.

From an evolutionary perspective, this singularity makes sauropods an intriguing anomaly. Evolution is rampant with examples of convergence, in which the same feature evolves more than once independently in different groups of organisms. A classic example of convergence is powered flight—flapping wings evolved in birds, bats, pterosaurs and insects, but the particular bones or other structures making up the wings differ among the groups, attesting to their independent evolutionary origins. Convergence in evolution is very common even when it comes to complicated features: warm-bloodedness, eyes that can move and focus, bipedal locomotion, the loss of limbs, the use of tools, and live birth all evolved multiple times in different animal groups. Convergence is widespread in the plant kingdom as well: carnivorous plants evolved at least a dozen times, roots evolved more than once, and even arborescence—plants taking the form of trees—evolved more than once. With convergence so common in nature, sauropods' uniqueness in size is special in itself. No other land animal has approached even a third of the largest sauropods' weight. What makes sauropods stand out from the crowd, both literally and figuratively?

Thanks to a wealth of sauropod discoveries over the past few decades, paleontologists are beginning to piece together the answer to this question. Analyses of this burgeoning fossil record reveal where and when these dinosaurs became giants, and the factors that allowed them to evolve extreme sizes again and again over the course of their nearly 150-million-year-long reign. They also suggest that, as mind-bogglingly huge as the largest-known sauropods were, even bigger ones remain to be discovered.

A GROWING FOSSIL RECORD

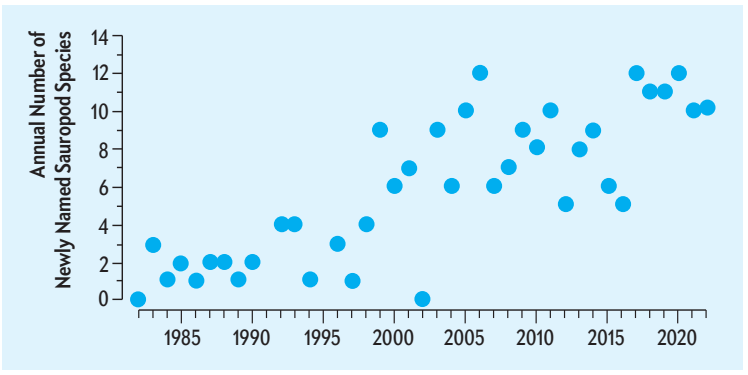
FIGURING OUT HOW sauropods evolved their uniquely enormous sizes has proved challenging because historically they had a relatively terrible fossil record—much worse than that of many other land animals and orders of magnitude worse than that of most animals that live in the sea. The first step in becoming a fossil is burial, and for immense sauropods that would have required an event that could deposit a lot of sediment on the body at once. Think landslides and flash floods, which might take place only a few times a decade or century in a given region, as opposed to the seasonal flooding of smaller streams and rivers that can bury



smaller animals multiple times a year. Compounding this problem, landslides and flash floods are violent affairs that scatter the fragile parts of an animal's skeleton. Sauropods had particularly uneven skeletons, combining dense limb bones as thick as tree trunks, vertebrae so riddled with air sacs that they resemble honeycomb, and small skulls composed of sometimes paper-thin bones.

There's a human element holding back the sauropod fossil record as well. A paleontologist can spend a field expedition digging up just a handful of sauropod bones or, in the same amount of time, scout and collect several skeletons of smaller creatures. Likewise, scientists can spend their finite research time in a museum waiting to get a single bone down from a shelf with a forklift or get straight to the business of studying the anatomy of a more sensibly sized animal. With limited time and grant funding, sometimes sauropods are skipped over.

Despite these hindrances, both the sauropod fossil record and our understanding of it have improved greatly over the past few decades. Throughout most of the 20th century, few new sauropods came to light. In the 1990s the situation began to change, as interest in dinosaurs ratcheted up and paleontologists undertook more excavations. Around the turn of the millennium, sauropod discoveries increased quickly. For the past decade researchers have commonly announced around 10 new species each year. With this better sauropod record available, we can finally start to study the evolution of their tremendous sizes.



Michael D. D'Emic, restyled by Jen Christiansen (*chart*)

TIPPING THE SCALE

TO FIGURE OUT WHY sauropods are so exceptional, we must first understand when, where and how they got that way. Currently there are about 250 sauropod species known from around the globe, and researchers continue to make important discoveries in areas that are relatively unexplored, such as Antarctica, and in areas that have been surveyed for decades, including Australia and North America.

From these new discoveries we know that sauropods' overall body proportions varied quite a bit. Some were slender like giraffes, and others were stocky like elephants. Some had necks that elegantly mirrored their tails, whereas others appeared unsettlingly off-kilter. Some had longer front legs than rear, giving them a stately appearance; others had low-slung shoulders, keeping their necks and heads near the ground. From their footprints we know that some sauropods walked with their legs near the midline like most quadrupeds; others held their legs farther out, like 50-foot-long French bulldogs. This diversity of body forms meant that multiple sauropods could coexist in the same ecosystems, with each species adapted to exploiting different resources within a given setting. We often find more than one sauropod species from a given time and place.

Their diversity of body forms also makes comparing the evolution of body size in terms of length or height tricky, so biologists turn to body mass (or weight) to make more equitable comparisons. Body mass is not just useful for making apples-to-apples comparisons. It also correlates with biologically important features such as metabolic rate, growth rate, nest clutch size, longevity and home range size. In this way, calculating body mass can give us an idea of these features of an extinct animal, so long as we are mindful of how fuzzy or sharp the correlation is.

Several methods exist for estimating body mass in extinct animals. The most popular is based on limb bone dimensions. Think of sauropod limb bones as columns supporting a building. Because the amount of weight supported by a column increases with thickness, we can estimate the mass of a sauropod based on the cross-sectional area of its limb bones. About 200 of the 250 sauropod species on record are known from fossils that include limb bones complete enough to measure this way.

I recently obtained these measurements and used them to chart sauropod body mass evolution. It turns out that over their long history, sauropods evolved a wide range of sizes. The largest include the truly gargantuan, such as the more than 50-metric-ton titanosaur *Patagotitan*. The smallest, such as the 20-foot-

Illustrations by Scott Hartman

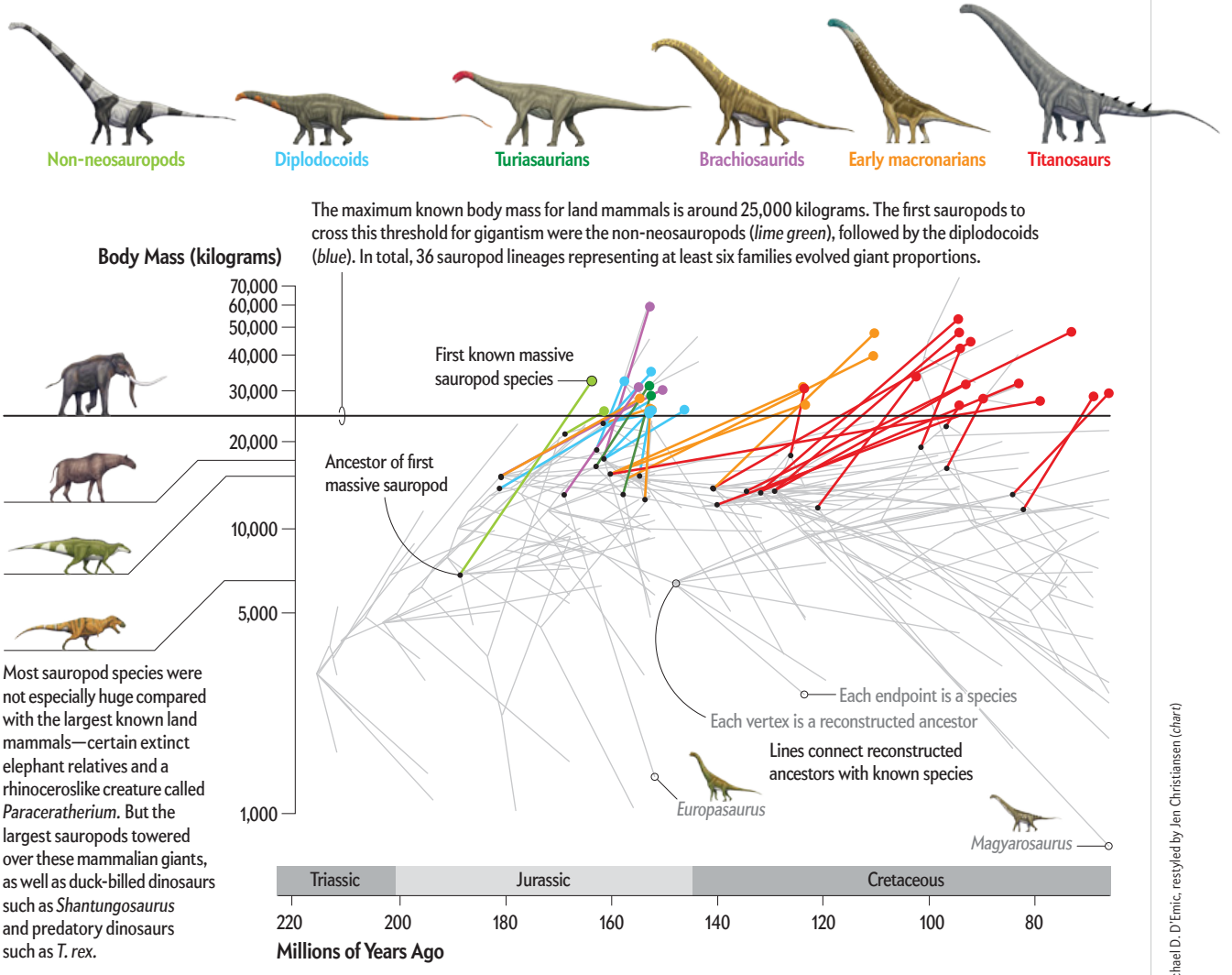
long *Magyarosaurus,* weighed only as much as a bull. I plotted these species on an evolutionary tree and stretched the tree over time to see when and how many times sauropods increased or decreased their body mass. When they first appeared more than 200 million years ago, they were relatively small—about the size of a rhinoceros. By around 165 million years ago the first giants, non-neosauropods, including the ultralong-necked mamenchisaurids, evolved.

Most sauropods were not exceptional in size compared with the largest terrestrial mammals. Consider *Diplodocus,* an especially long-tailed sauropod that inhabited western North America around 155 million to 145 million years ago. The *Diplodocus* specimen known as "Dippy," replicas of which are exhibited in museums around the world, weighed a paltry 14 tons in life, smaller than the largest mammoths or rhinoceroslike mammals of the past. Dippy's weight is close to the average sauropod body mass. Like Dippy, three fourths of all sauropods weighed less than the largest land mammal.

From this relatively modest stock, I found, sauro-

Becoming Giant Again and Again

Sauropods evolved a wide range of sizes over the course of their nearly 150-million-year reign. The earliest ones were relatively small, around the size of a rhinoceros. The first giants emerged by 165 million years ago. In the span of 100 million years, sauropods evolved enormous sizes—with masses of more than 25,000 kilograms—36 times. Each new family gave rise to one or more lineages that became huge. These largest sauropods differed from one another in the shape of their teeth and heads and in their body proportions, indicating that they ate different things—and thus occupied different ecological niches.



Michael D. D'Emic, restyled by Jen Christiansen (*chart*)

Illustrations by Scott Hartman

pods evolved their record sizes a remarkable three dozen times on six landmasses over the course of 100 million years. Sauropods evolved their hallmark sizes early on, and with each new family to evolve, one or more lineages independently reached superlative status. This filling and refilling of the "extremely large body" niche mirrors the pattern seen in land mammals, which evolved very large body sizes quickly in the wake of the dinosaur extinction, before plateauing in the gigantic-mammoth range.

The largest-of-the-large sauropods had differently shaped teeth and heads and distinctively proportioned bodies, indicating that these herbivorous dinosaurs ate different plants and lived in subtly different habitats. In other words, like sauropods in general, the heftiest sauropods occupied somewhat different ecological niches from one another.

THE LIMITS OF EVOLUTION

THE SHEER SIZE of the biggest-known sauropods raises fascinating questions about the limits of evolution: Just how big can animals get on land? And why can't they get bigger than that? Biomechanical studies provide some hints. Mobility decreases as limb bones increase in thickness to support a larger animal's weight, so there is an upper limit to how thick limb bones can be while still supporting a functional animal. From a physics perspective, research by Jyrki Hokkanen of the University of Helsinki suggests that the theoretical limit for terrestrial body mass based on biomechanics is well over 100 metric tons. Over the years, murky reports of a few now-lost fossils have hinted at the existence of sauropods with masses greater than that. But the largest definitive sauropod, the exceptional 75-metric-ton *Argentinosaurus,* doesn't approach that limit. In addition to biomechanics, factors such as resource and habitat availability and heat dissipation also limit maximum body mass in complex and interacting ways that are difficult to predict. For now all we can say is that terrestrial animals could get at least as big as *Argentinosaurus* and most likely bigger. It is probably only a matter of time before sauropods larger than *Argentinosaurus* are discovered.

To reach their record sizes, sauropods underwent record growth. They had the most growing to do of any animal (in an absolute sense), passing through four orders of magnitude in body mass. They had to grow so much not only because their adult body sizes were huge but also because they started out so small. Like other dinosaurs, including modern birds, sauropods hatched from eggs. The larger an egg is, the sturdier the shell needs to be. But evolution can thicken and strengthen eggshell only so much because the shell must allow for gas exchange and the eventual exit of the hatchling. These demands greatly restrict egg size. Sauropod eggs were cantaloupe- to basketball-sized, smaller than those of the biggest birds. Even a 100-foot-long sauropod started out life just a foot or two long. In contrast, placental mammals, which give birth to live offspring, have young that start out relatively large. For example, blue whale calves are around 20 to 25 feet long when they are born, so they must approximately quadruple in length to reach their adult size—a modest task compared to the perhaps 100-fold increase in length set before a hatchling sauropod.

Studies of the bones of several sauropod species have revealed how they accomplished this growth. Just as trees contain rings that can be counted to determine their ages and growth histories, bones

PATAGOTITAN, discovered in Argentina in 2010, is one of the largest sauropods on record. It weighed an estimated 50 metric tons or more.

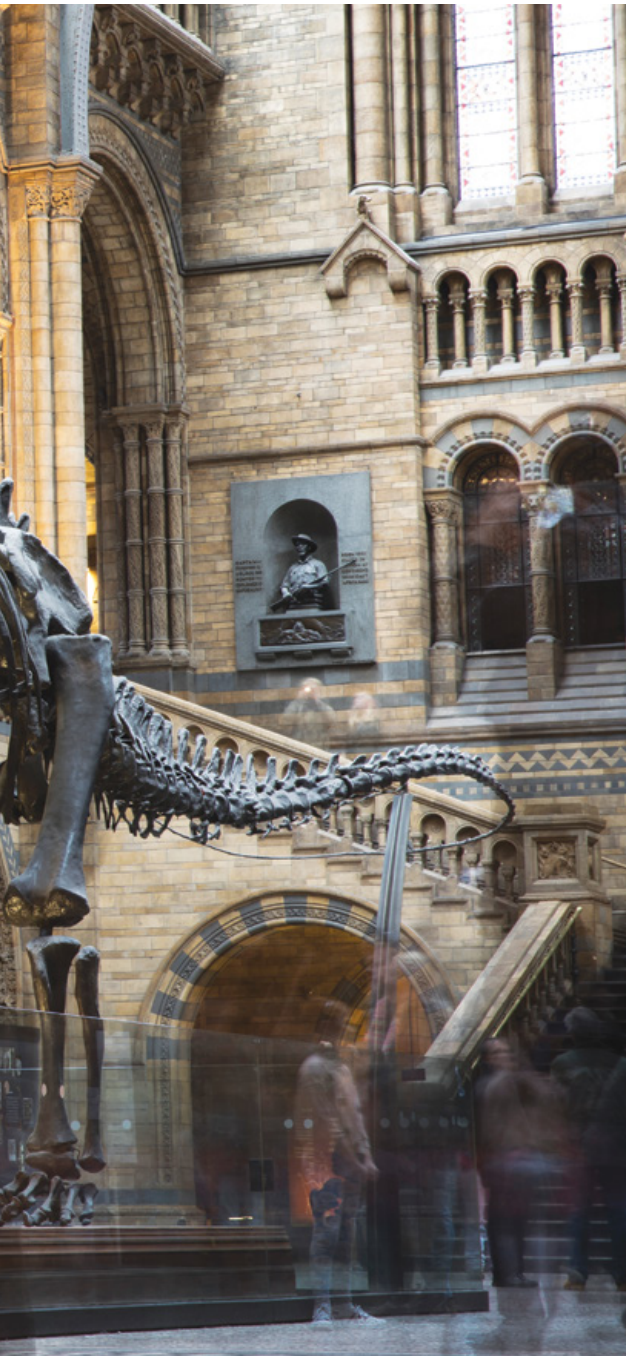
© chrisstockphotography/Alamy Stock Photo

DIPLODOCUS, the most common sauropod exhibited in museums, inspires awe for its size. At around 14 metric tons it weighed only a sixth as much as the largest sauropod, however.

contain rings that record a vertebrate animal's age and its rate and duration of growth. Modern-day vertebrates exhibit a variety of growth strategies. Reptiles, including alligators, lizards and turtles, grow relatively slowly, whereas large mammals such as the blue whale grow rapidly. If sauropods grew at the relatively sluggish rates that reptiles do today, it would have taken a century or more for them to reach their immense sizes. Instead, as the growth rings reveal, they grew impressively quickly—on par with the growth rates seen in many large mammals today—attaining adult size in 20 to 50 years.

Sauropods probably needed to grow fast because although adults may have been safe from predators, hatchlings were easy prey that had to compete with other groups of dinosaurs and animals for resources. Unlike large mammals such as whales, which spend years raising each calf, sauropods pursued a quantity-over-quality approach to reproduction, producing lots of eggs and then leaving their young to fend for themselves. Fossils show that at least some groups of sauropods nested in colonies and built their nests quite close together—too close for an adult to pass between—which would have prevented parental care.

Dan Kitwood/Getty Images



The faster hatchlings could grow, the better their odds of surviving predators.

That said, sauropod growth rates varied quite a bit from species to species. As sauropods initially evolved larger sizes, they did so by growing faster during annual growth pulses while pausing growth during unfavorable seasons, like most animals do. Later sauropods seem to have further adapted by eliminating or minimizing seasonal pauses and growing quickly throughout the year, according to research carried out by Cecilia Alpadetti of the National University of San Juan in Argentina and her colleagues. Migrating to areas where food was available year-round could have facilitated this sustained growth. A research team I was part of recently showed that some sauropods likely migrated great distances, for example from the Great Lakes region to the Rocky Mountains. The ability to continue growing throughout the year may have been a key innovation, sustained by great migrations, that facilitated the emergence of gigantism in early sauropods.

WHY SUPERSIZED?

WE ARE ONLY JUST beginning to understand why sauropods got so big. The answer seems to be complex, with no single way to explain the existence of all of the largest-of-the-large species. Like all dinosaurs, sauropods exhibited a mix of characteristics found in today's reptiles, birds and mammals. A large team led by a group of researchers from the University of Bonn in Germany has shown that some of the sauropods' more "reptilian" traits are probably what allowed them to become the largest animals ever to walk on land. Sauropods had simple teeth incapable of chewing, which meant they could ingest food quickly and ferment it in their gut, as evidenced by their voluminous rib cages. Not chewing also meant they didn't need bulky jaw muscles, so their heads could stay small. That arrangement, in turn, allowed for the evolution of a longer neck, which let them reach wide swaths of food without moving much—a very energy-efficient way of life. Reproducing by laying eggs and not caring for their young allowed sauropods to focus their energy and resources on growth.

Sauropods also independently evolved a birdlike lung with air sacs throughout their bodies, making their breathing more efficient and their bodies lighter for their size. Many large sauropods were upward of 10 percent air inside, overall.

Their long necks and small heads, lack of parental care, and air-filled bodies explain why sauropods are bigger than other land animals in general. But these traits don't explain why 36 lineages within the sauropod group surpassed the other lineages to attain truly epic proportions. Each case seems to have been distinct—predation pressure may have led to the evolution of increased growth rates in one instance, resource abundance could have allowed for extended growth seasons in another—and will require a lot more study to solve.

So much about sauropods is awe-inspiring: they pushed the bounds of biological possibility not once but dozens of times. With an ever improving fossil record, we hope to soon understand some of the evolutionary pressures that led sauropods to become, over and over, the largest land animals of all time. SA

FROM OUR ARCHIVES

Triumph of the Titans. Kristina A. Curry Rogers and Michael D. D'Emic; May 2012.

scientificamerican.com/magazine/sa

POLYMETALLIC NODULES from the deep ocean floor are rich in valuable minerals such as cobalt and nickel.

ENVIRONMENT

DEEP-SEA DILEMMA

Mining the seafloor could boost production of clean energy technology. It might destroy irreplaceable ocean ecosystems in the process

By Olive Heffernan

Photographs by Vincent Fournier

Olive Heffernan is a science journalist based in Dublin, Ireland, and author of a book about the high seas, forthcoming in the spring of 2024.

BIZARRE CREATURES FROM THE BLACK OCEAN ABYSS, PRESERVED IN GLASS JARS, LINE STACKS OF shelves in deep-sea biologist Adrian Glover's laboratory at London's Natural History Museum. Among them is a ghostly white animal, oddly elegant and shaped like an ornamental flower with a glass stalk, retrieved from the bottom of the Pacific Ocean, five kilometers down. Ninety percent of the species Glover has assembled had never before been seen by humans.

Glover is part of an international effort to discover what lives on a remote part of the Pacific Ocean seafloor called the Clarion-Clipperton Zone. The CCZ is a vast abyssal plain slightly larger than the European Union, situated between Mexico and Hawaii, dotted with rocky outcrops and seamounts. It is one of the most pristine and least explored parts of our planet—and it may soon endure the world's first deep-sea mining operation.

Trillions of black, potato-size rocks known as polymetallic nodules are strewn across the CCZ seafloor. The nodules contain valuable metals, including cobalt, copper and nickel needed for electric vehicles; rare earth elements crucial for clean energy technologies; and smaller amounts of lithium, in high demand for batteries. Surveyors expect the overall tonnage across the CCZ to be substantial, in some cases higher than the sources now mined on land.

Glover hands me a nodule, which looks and feels like a small lump of coal, cold and lifeless. On closer inspection I can see faint traces of foraminifera, single-cell organisms fundamental to the marine food web, which once covered its surface. Each nodule starts as a little fragment, perhaps a shark's tooth or a piece of seashell. Over a long time, metals slowly gather and form an expanding crust around this node, growing just one to 10 centimeters every million years. The specimen in my hand would have taken about 10 million years to form.

Out on the soft CCZ seafloor, nodules offer a hard surface for tiny creatures, from microbes to sponges, to cling to—a life-giving substrate in a severe habitat. Water temperatures can reach zero degrees Celsius, there is virtually no light, and pressures can exceed 1,000 bars, equivalent to having a couple of elephants standing on your big toe. The minuscule life attracts other animals; octopuses, for example, lay eggs in the sponges. Over time, unique communities form across seafloors strewn with nodules.

Life in the CCZ doesn't exist in great abundance, but it does exist in great diversity. The nodules "are home to hundreds, maybe thousands, of species that we know little about," Glover says. "Whether they would provide food on a plate or stop climate change or become the next cure for cancer, we can't say yet. Though we could do the research to find out."

Not everyone wants to wait for more discovery. A Vancouver-based start-up called The Metals Company (TMC) is pushing to start mining the CCZ in 2024, in partnership with the Pacific Island nation Nauru. Big machines would scrape the seafloor, scooping up nodules while kicking up clouds of sediment, potentially damaging the deep sea on a vast scale by removing habitat and species and altering ecosystems.

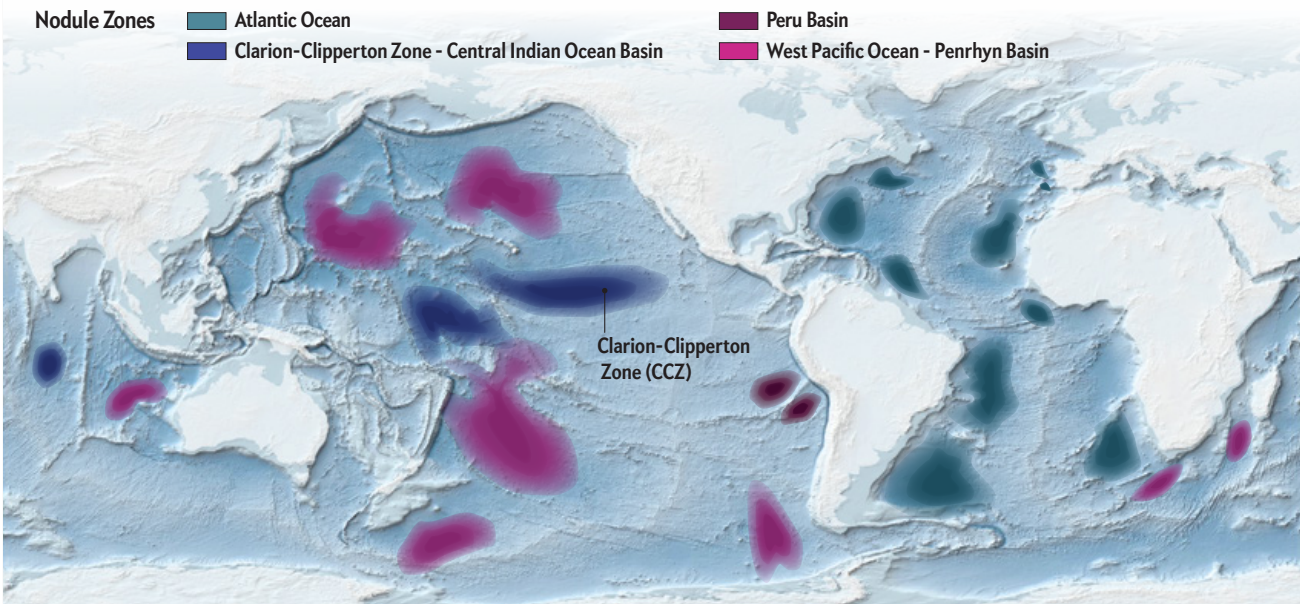
Whether TMC goes ahead with its plans is up to the International Seabed Authority (ISA), a United Nations–affiliated agency responsible for promoting deep-sea mining in international waters while also protecting the deep sea from harm. ISA has not finalized its mining code, so deep-sea miners such as TMC have no guidelines about how they should operate. There are significant unknowns about potential environmental damage, as well as about what lives in this remote part of the Pacific and how the region may contribute to ocean health. Given ISA's conflicting mandate, many experts are concerned that it will prematurely green-light commercial extraction because of industry pressure.

It's not just environmentalists who are concerned; governments and even corporations that want the minerals in the nodules have taken a stand against mining in international waters, at least until the potential impacts of deep-sea mining can be fully assessed. The growing chorus of voices includes France, Germany and Chile; BMW and Google; and more than 700 experts. Scientists such as Glover are scrambling to collect data, in many instances funded by contractors, including TMC, which need it to obtain mining approval. "The rush to understand this place has been related to the fact that we may lose it," says Diva Amon, a deep-sea biologist at the University of California, Santa Barbara.

AN ANIMAL called a crinoid, or sea lily, inhabits the seafloor 4,800 meters deep, in the central Pacific Ocean's Clarion-Clipperton Zone, targeted for mining.

Where the Nodules Are

Polymetallic nodules—small rocks containing valuable minerals—can be found in abundance on various regions of the deep seafloor. The U.S. Geological Survey has identified four zones where prospects are high. Each zone represents a unique combination of the likely concentration of nodules and the likely density of metals in them, extrapolated from samples and seafloor characteristics. The International Seabed Authority has granted 17 of its 30 exploration licenses in the Clarion-Clipperton Zone.



SUNKEN TREASURE

GERARD BARRON, CEO OF TMC, describes a polymetallic nodule as a "battery in a rock." The self-assured prospector says deep-sea mining is a rare opportunity to transition the world off fossil fuels. His company has secured the rights to explore for minerals across several large tracts of the CCZ—enough metals, he claims, to power 280 million electric vehicles, equivalent to the entire U.S. car fleet. Prospectors note that deep-sea mining could be the start of ethical mineral extraction: doing away with child labor linked to terrestrial mines in some countries, providing revenue to developing nations through deep-sea profit sharing and leaving a better environmental legacy than mining has on land.

No one has yet scoured the deep sea commercially, but exploration is happening in national and international waters. Norway, for example, has recently proposed opening its continental shelf to mining. ISA, which presides over the international seabed, has granted 30 exploration contracts covering 1.4 million square kilometers of the seafloor to prospective miners. Of those, 17 are for sites in the CCZ; each plot measures around 75,000 square kilometers, roughly the size of Ireland. The other contracts cover nodules in the Western Pacific Ocean and Indian Ocean, as well as massive sulfide deposits at hydrothermal vents in the Atlantic and Indian Oceans, and cobalt crusts that line the flanks and summits of seamounts at various Pacific sites.

TMC has contracts to explore three CCZ plots for nodules, in partnership with sponsoring states Nauru, Tonga and Kiribati. In June 2021 TMC and Nauru, through a venture called Nauru Ocean Resources, Inc. (NORI), invoked an arcane ISA statute known as the two-year rule, which obligates ISA to allow mining to proceed within two years, regardless of whether a mining code is in place. In theory, TMC could have begun commercial extraction in July.

In November 2022 the company completed its first trial; onboard the 228-meter-long mining vessel *Hidden Gem,* Barron's team hauled up more than 3,000 metric tons of nodules from 4.3 kilometers underneath the ocean's surface, proving that it is ready, and equipped, to start commercial work.

TMC is the likely frontrunner in the race to mine the deep sea because it is the only contractor to have invoked the two-year rule. Barron plans to start in 2024. The company rose from the ashes of Nautilus Minerals, a Canadian start-up headed by a geologist and friend of Barron's named David Heydon, who subsequently founded DeepGreen, later rebranded as TMC. Barron was one of the early Nautilus investors. Nautilus intended to excavate minerals from hydrothermal vents, often teeming with exotic life, in Papua New Guinea's territorial waters. The start-up developed and tested three big mining machines, each the size of a combine harvester and weighing about six metric tons,

Source: "Estimates of Metals Contained in Abyssal Manganese Nodules and Ferromanganese Crusts in the Global Ocean Based on Regional Variations and Genetic Types of Nodules," by Kira Mizell, James R. Hein, Manda Au and Amy Gartman, in *Perspectives on Deep-Sea Mining*, edited by Rahul Sharma. Springer, 2022 *(reference)*

Map by Jo Hannah Asetre

which quickly came to symbolize the damage industry could impose on the ocean floor. Faced with issues related to securing a vessel, as well as lack of investment, in 2019 the company liquidated.

Barron, who got out before Nautilus went bust, has cast himself as a green miner. The 56-year-old Australian exhibits the casual ease of a Silicon Valley tech mogul: tight beard, shaggy hair, jeans and white T-shirt. He also wears a combat-style jacket, inside which he carries a softball-size polymetallic nodule—a portable prop for his pitches. When he talks about his company's plans, Barron exudes confidence and calm optimism. "I think it's important to remember that we're doing this because the world agrees that we should move away from fossil fuels," he told me when we met recently at a café in west London. "That transition is going to be very, very metal-intensive."

Prospectors contend that without deep-sea mining the world will run out of valuable metals for green technologies. According to the World Bank, we'll need more than three billion (nonmetric) tons of minerals and metals to deploy the wind, solar and geothermal power required to avoid two degrees C of global warming. Some estimates predict that the reserves of cobalt, used widely in rechargeable batteries, and of nickel, used in electric vehicle batteries and renewable energy storage, in the CCZ are significantly larger than the remaining reserves on land, although it's hard to gauge the real extent of resources in the abyss, especially those that are easily recoverable.

Not everyone is convinced of an impending shortage—or that, in the event of one, deep-sea mining is the only solution. The Institute of Sustainable Futures says a global transition toward 100 percent renewable energy could be met with land-based reserves. "Urban mining"—recovering metals from our discarded computers, mobile phones, tablets and other electronics—could also be greatly scaled up. The world recycles less than 20 percent of its electronic waste, and safe disposal is a rapidly growing problem. Also, future demand for certain metals, such as cobalt and lithium, may not be as high as once anticipated; Tesla now uses cobalt-free batteries in half of its new cars. Manufacturers are exploring alternatives to lithium-based batteries, too.

SMOTHERED BY SEDIMENT

IF THE 17 CCZ EXPLORATION contracts all progress to exploitation, it's possible that within a decade, multiple operators will be dredging the seafloor for nodules. Most operators, including TMC, would use harvesters to mine the dark seafloor. A typical harvester is fitted with twin caterpillar tracks like those on an army tank so it can crawl across the seabed sediment. The harvester sucks up nodules, whipping up a cloud of fine silt as it travels along, and sends them to a surface vessel through a pipe called a vertical riser. An average harvester would gather about 400 metric tons of nodules per hour from the CCZ floor; that's 67,000 metric tons per week. One machine, over a 30-year contract, the standard duration, could strip 10,000 square kilometers (3,900 square miles) of seabed.

Some upset is certain. Given the incredibly long time it takes nodules to grow and their role as a substrate for marine life, "it's very clear that if you take the nodules away, the ecosystem would move to a different state for millions of years," says Sabine Gollner, a research scientist at the Royal Netherlands Institute for Sea Research.

As the big machines crawl along, they will suspend large amounts of fine sediment in the water, which could settle as much as tens of kilometers away. Scientists have little evidence for what the effects might be, but it is plausible the plume could smother sedentary creatures such as sea anemones and sponges. Barron cites a 2022 study led by the Massachusetts Institute of Technology that found that the sediment plume kicked up by mining vehicles didn't disperse as widely as people thought it would. But that was from an experimental trial with a prototype collector about one-third the size of an actual machine.

Sediment stuck to the nodules is sucked up along with them to the surface vessel. Onboard, the nodules would be cleaned before being transported to a shore-based facility for processing, and the waste sediment would be pumped back into the ocean through another long pipe. To save on expenses, most contractors plan to release this "dewatering plume" at around 1,000 meters above the ocean floor. This rain of sediment is likely to cause problems for midwater swimmers, such as jellyfish, by interfering with their visual communication cues or their ability to filter food from the water. It could also clog the gills of commercial species that forage there, such as fish and shrimp, which are eaten by larger species like tuna and billfish.

Barron's response to environmental concerns is that land mining creates extensive ecological damage and in some places involves human labor abuses. He points to the growth in nickel mining in the world's equatorial rain forests, notably Indonesia and the Philippines, which studies have shown seriously harms ecosystems there. "You can't look at one [environmental] situation without having an eye on the other," he contends.

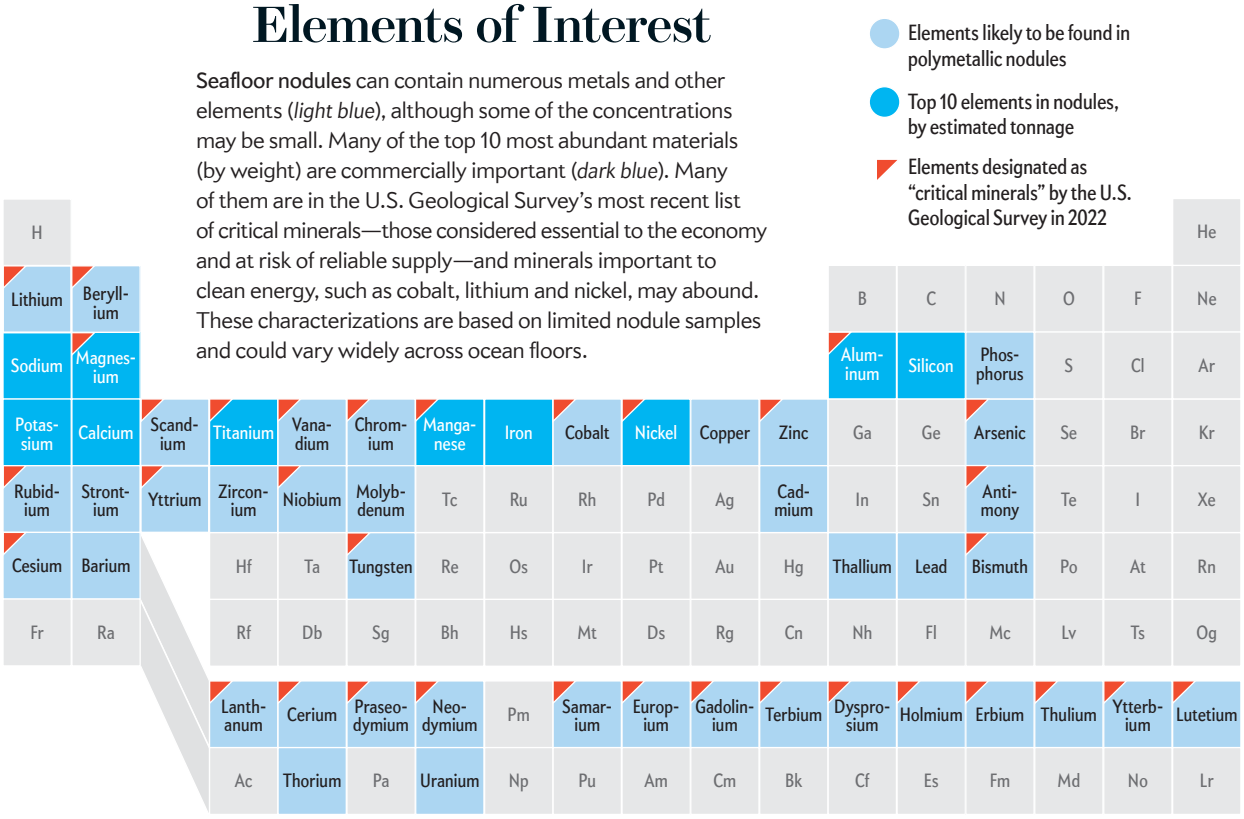
WEAK SCIENCE

UNDER ISA RULES, contractors have up to 15 years to explore their claim areas. They must conduct a "baseline survey" of the nodules and the environment—including details of the habitat and what lives there—and submit it to the ISA's Legal and Technical Commission as part of their exploitation application. The type and amount of data included in the survey, however, are left up to the contractors, based on ISA guidelines, and the commission is still discussing what data might be acceptable.

Some mistrust stems from the fact that ISA has never refused an application for exploration, even in regions recommended as marine-protected areas by international conservation organizations. One especially contentious case is a 2018 contract awarded

Elements of Interest

Seafloor nodules can contain numerous metals and other elements (*light blue*), although some of the concentrations may be small. Many of the top 10 most abundant materials (by weight) are commercially important (*dark blue*). Many of them are in the U.S. Geological Survey's most recent list of critical minerals—those considered essential to the economy and at risk of reliable supply—and minerals important to clean energy, such as cobalt, lithium and nickel, may abound. These characterizations are based on limited nodule samples and could vary widely across ocean floors.



to Poland to explore a vast site in the mid-Atlantic, next to and partly in the site of the Lost City hydrothermal field—one of the most extreme environments ever discovered on Earth, which scientists hope will be considered for World Heritage status.

Diva Amon, a biologist from Trinidad, is one of ISA's most vocal critics. She says the agency's requirements for contractors are far too weak. Amon's first postdoctoral research position, at the University of Hawaii, took her to the CCZ, where—like Glover—she was collecting biological data from a site targeted for mining, in her case by UK Seabed Resources, then a subsidiary of the arms giant Lockheed Martin. In 2017 Amon founded SpeSeas—a nonprofit dedicated to raising ocean awareness—and in 2020 she was named a National Geographic Emerging Explorer. She starred alongside Will Smith in the actor's documentary series *Welcome to Earth*. Now at U.C. Santa Barbara, Amon focuses on understanding the deep sea, including the CCZ; she is no longer collecting data for contractors.

Amon says "there's a fundamental difference between science to understand and science to exploit"—something she has learned from working in both situations. She says science to exploit often becomes "a tick box exercise"—doing only what's needed to satisfy a checklist. The problem with that, Amon says, is "not all contractors are doing high-quality science. Not all contractors are doing a lot of science. And not all contractors are making their science accessible." Malcolm Clark, a biologist who has served as an adviser on the ISA's Legal and Technical Commission for the past seven years, agrees.

TMC has conducted several baseline surveys of one of its three CCZ sites, called NORI-D, collecting data on the density and location of the nodules, and the area's habitat and biology. In March 2023 it submitted the first tranche of these data to ISA, saying it intended to submit the remaining data before August 2023. Amon claims the information is insufficient. "A big part of understanding a place—especially a place that you've never been to—is understanding the variation over a [long] period of time," she says.

Renee Grogan shares some of Amon's frustrations with the ISA. She is co-founder and chief sustainability officer of Impossible Metals, a start-up that is promoting what it calls a less intrusive extraction method—using a fleet of autonomous robots to pick up nodules individually from the seafloor rather than sucking up everything in a machine's path. ISA should force transparency from contractors, says Grogan, who previously worked on sustainability for Nautilus Minerals. "Regulators with backbones" are needed for that to happen, she says.

Another concern about ISA's conflicting mandate

Sources: "Estimates of Metals Contained in Abyssal Manganese Nodules and Ferromanganese Crusts in the Global Ocean Based on Regional Variations and Genetic Types of Nodules," by Kira Mizell, James R. Hein, Manda Au and Amy Gartman, in *Perspectives on Deep-Sea Mining*, edited by Rahul Sharma. Springer, 2022 (*nodule data*); "2022 Final List of Critical Minerals," by U.S. Geological Survey (*reference*)

Graphic by Jen Christiansen

to regulate and promote mining is that ISA recommends, but does not require, that contractors conduct small-scale tests of their operation's potentially harmful impacts. Clark says few contractors could afford the financial risk without any surety they would be licensed. "Going into test mining is a huge increase in the complexity and the expense of what a contractor might need to do," he says. He acknowledges that very little is known about the impacts mining could create. "That's obviously a very big question, as you start to move from a few hundreds of [metric] tons of resource extraction into thousands and millions of tons over much larger areas."

Barron claims that nodule mining could have a regenerative effect on marine life. "What we're finding now is that actually, when you do disturb an area, it creates much more attraction … for organisms to come back," he says. "Once we start to collect nodules, the area starts to rehabilitate pretty well straight away." Without mining having been done, it is hard to substantiate such a claim. A 2022 project Barron referred to, which involved a few mining study sites, looked only at foraminifera and found no statistical difference between sites, whether mined or untouched. When queried, TMC responded in writing that "further study of the impacts of actual collection system tests, such as those NORI is undertaking, [is] essential."

MISSING DATA

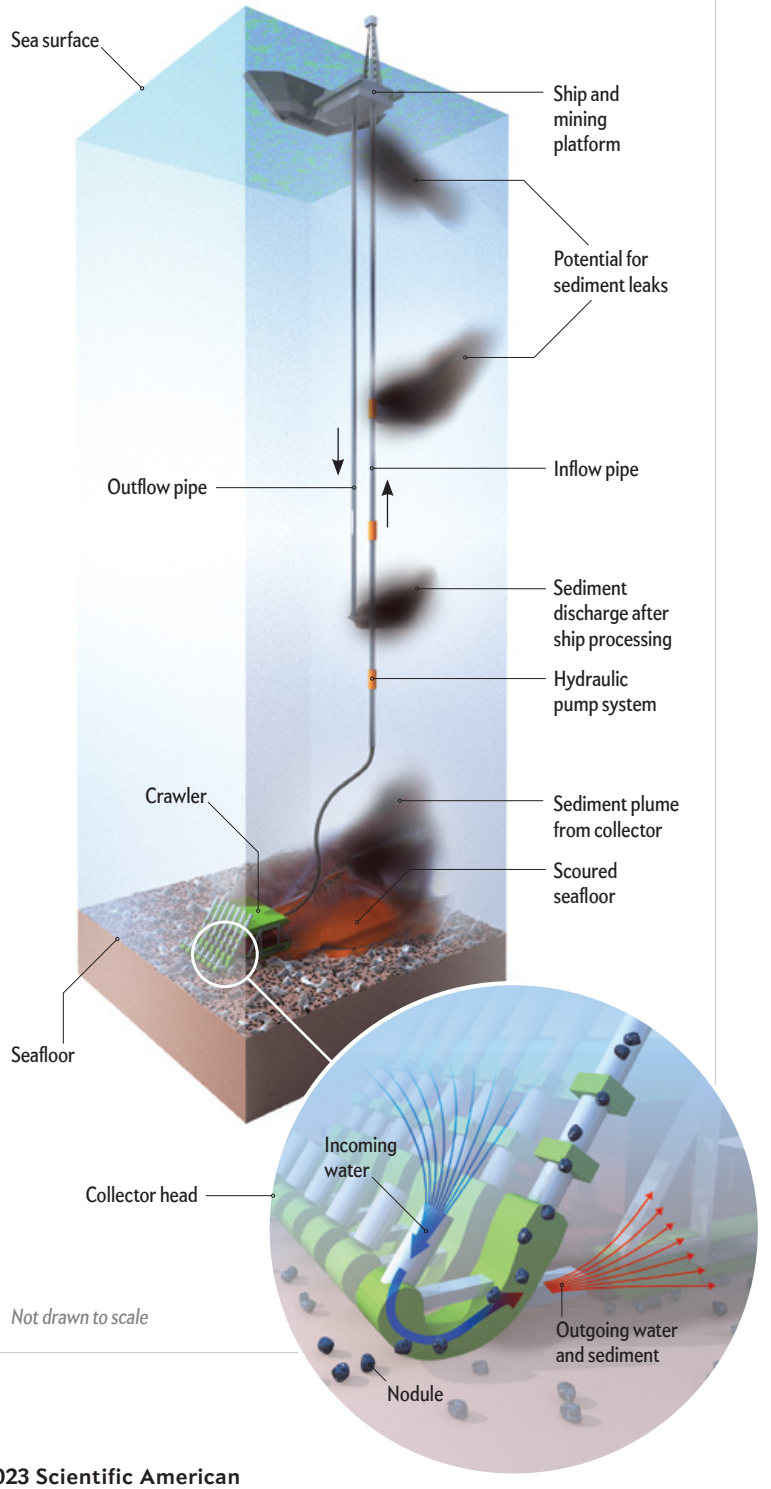
IN MARCH 2022 Amon led a review, with 30 other scientists, to identify categories of information needed to manage a mining operation, including how animals that live there vary over time and space and their relationships to one another, as well as noise and light pollution, sediment plumes and the release of toxic metals. One issue was whether a contractor or the regulator has an effective management plan in place: If there is an adverse impact, whose job is it to mitigate the consequences? The study concluded that, for the CCZ, sufficient data to sustainably manage a mining operation exist for only 15 percent of the categories. Filling in the knowledge gaps would be a "monumental task" that could take a decade or more, the experts wrote. Ten of the 30 authors support a moratorium.

One unanswered question is how mining will impact life in the water column. Jeff Drazen, a biologist at the University of Hawaii whom TMC has contracted to collect biological data in the CCZ, worries that this issue is being ignored. "Despite a lot of scientists wanting to monitor [midwater] biology, we were not asked to do that. So that has still not happened," he says, noting that contractors have not required it. Drazen says that when TMC tested its mining equipment in NORI-D there was no capability on the ship to look at impacts on midwater life.

Another open question is whether mining will impact the survival of isolated populations. For example, one strategy to maintain deep-sea diversity might be to rake long strips of seafloor that are separated by

How Deep-Sea Mining Works

Heavy harvester machines, the size of a farm combine rolling on caterpillar treads, crawl along the seafloor scouring the surface and life on it, vacuuming up nodules and kicking up a cloud of sediment. Nodules are pumped up to a surface vessel, where they are cleaned before transport to shore. Waste sediment is discharged down a pipe into the water column. The sediment plumes could make it hard for animals and plants to breathe or filter food. Other designs are being considered.



Not drawn to scale

Source: "Towards Deep Sea Mining—Impact of Mining Activities on Benthic Pelagic Coupling in the Clarion Clipperton Fracture Zone," by Benjamin Gillard. Ph.D. thesis, Jacob's University: November 2019 (*reference*)

Graphic by Violet Isabelle Frances for Bryan Christie Design

intact strips. But would the newly isolated populations be able to survive?

Barron says Amon's review is flawed, claiming it includes only the views and data of select experts and excludes contractor data, which he says show that mining impacts are likely far less than once feared. In reply, Amon says contractor data were mostly missing from DeepData, the platform ISA uses to house information. "It may be true that there are more data out there. But they are not accessible to any stakeholders in a meaningful way," says Beth Orcutt, a marine biologist at the Bigelow Laboratory for Ocean Sciences in Maine.

According to ISA more than 100 CCZ surveys have been done. Data from just 24 of them reside on DeepData. A recent study led by Muriel Rabone, a data curator at London's Natural History Museum, unearthed problems with the biological information stored on the platform, including duplication of records and misidentification of species. Rabone has communicated her concerns to ISA and says the regulator is working hard to fix the problems. Rabone says that until corrections are made, experts analyzing the data could reach false conclusions.

TRUST

BARRON REMAINS outwardly optimistic that mining will start soon, even though the past few months have been tough for TMC. In March the International Union for the Conservation of Nature, with 160 member countries, urged ISA members to back a moratorium on deep-sea mining. In May the shipping company Maersk, an investor in TMC since Barron became CEO in 2017, announced that it was divesting, without detailing reasons why. TMC's share price has been volatile in recent months. Still, now that the two-year rule's embargo date has passed, TMC could just begin mining, without ISA having finalized its regulations, as long as there is no veto from ISA member nations indicating a need to wait for those guidelines.

Scientists hope the effort being made to understand the ocean's abyss will lead to an informed decision. "There has to be a level of trust that [contractors] are doing it correctly and reporting it correctly," Orcutt says. "So much of deep-sea mining is going to rely on trust because no one can go out there and watch what they're doing." A crucial consideration for ISA will be deciding how much evidence about harm is enough. "This is essentially a decision as to what level of risk people are prepared to accept," Glover says. "We're never going to answer every question."

Mining's larger future will rest largely on how ISA finalizes its rule book amid the rush to scour the seafloor. ISA has a rare chance to regulate an industry before the industry has begun. SA

FROM OUR ARCHIVES

It's Time for Ocean Zoning. Tundi Agardy; Special Editions, June 2009.

scientificamerican.com/magazine/sa

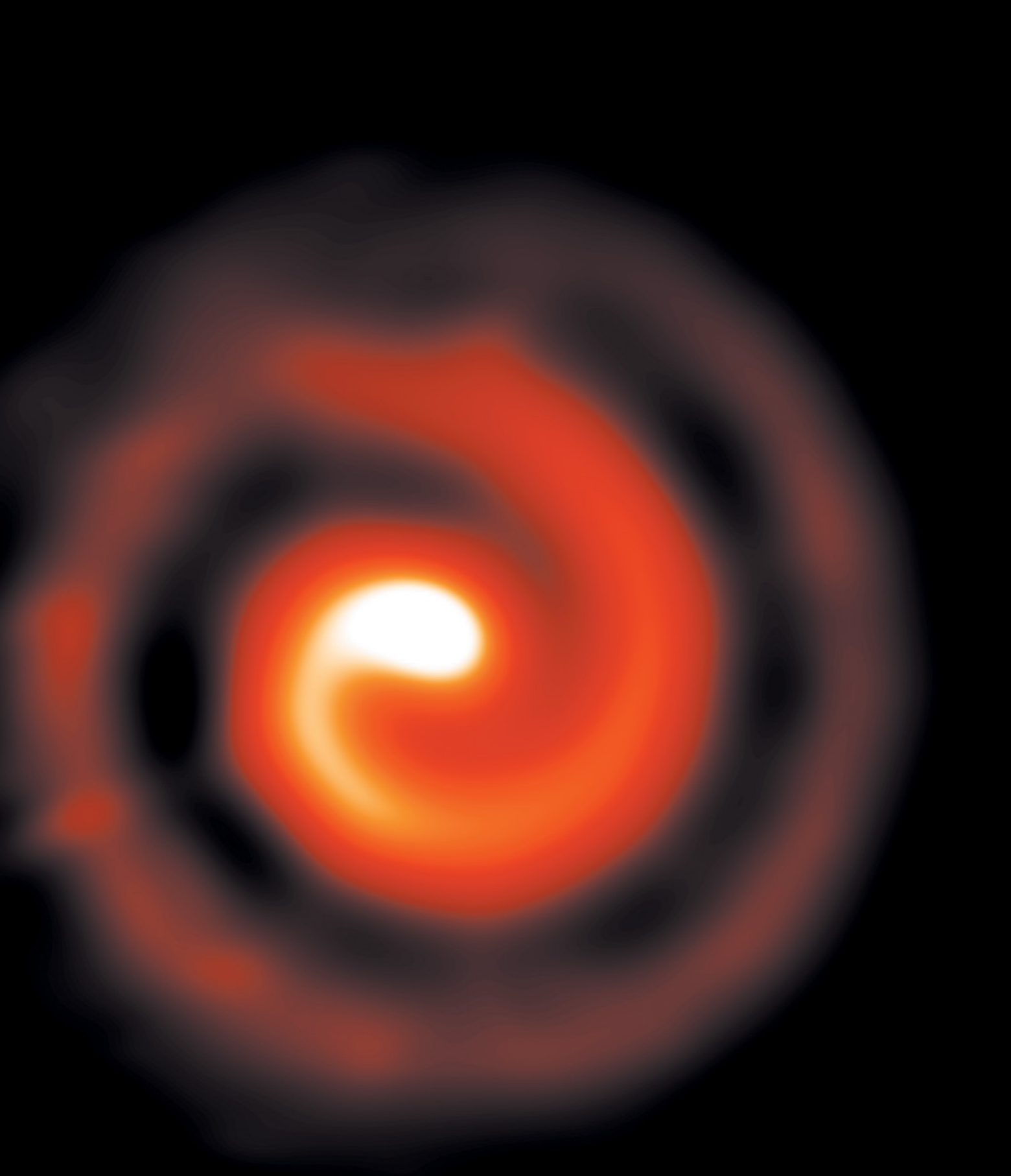
CREATURES from the Clarion-Clipperton seabed include (*left to right*) a sea cucumber (*purple*), a different sea cucumber (*white*), a glass sponge, a sea star and a sea anemone.

Celestial Wonders

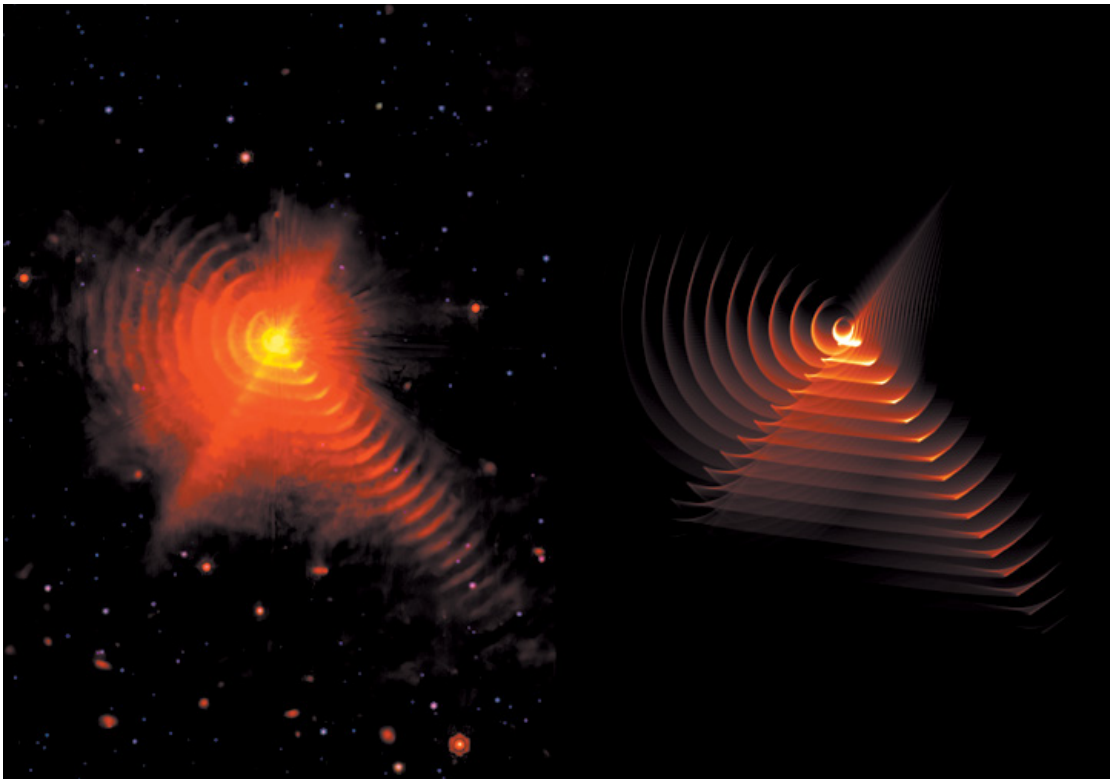
A class of rare, doomed stars enshroud themselves in mystery

By Peter Tuthill

ASTRONOMERS TEND TO EXHAUST SUPERLATIVES WHEN THEY TALK ABOUT THE ferociously hot and luminous stars known as Wolf-Rayets, which are among the largest, hottest and rarest stars in the universe. Wolf-Rayets are believed to be the final, fleeting stage in the lives of the most massive stars—those starting life with anywhere from 20 to more than 200 times the mass of the sun. These heavyweights are blue and incredibly luminous, burning rapidly through vast reserves of hydrogen fuel with live-fast, die-young abandon. As they burn up, they eject huge amounts of mass in dense, fast winds that flow at astonishing speeds. When they run out of this fuel, these stars collapse under their own gravity in the cataclysmic events we observe as supernovae.



A SPIRAL DUST PLUME streams off the WR 104 binary-star system, as seen in infrared.



AN INFRARED image from the James Webb Space Telescope (*left*) shows the peculiar ripples of dust surrounding the WR 140 star system. The photograph closely matches a numerical simulation (*right*) depicting 15 successive dust shells puffed out at intervals coinciding with the system's eight-year binary orbit.

Their extreme nature marks them as celestial outcasts that cluster at the borders of astronomy's foundational chart, the Hertzsprung-Russell diagram, which maps stars by their brightness and temperature. Wolf-Rayets rise above and beyond the diagram's "main sequence," where ordinary stars congregate. They are bloated monsters with surface temperatures that can exceed 200,000 kelvins—30 times hotter than the sun—and radiation fields that can outshine the sun by factors of more than a million.

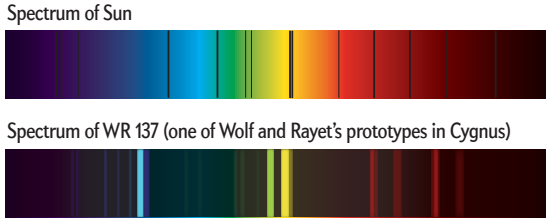
The defining trait of a Wolf-Rayet star—a low abundance of hydrogen—turns out to be a harbinger of doom. After a star exhausts its hydrogen, it will start burning other fuels, such as helium, but this gains the star only a modest stay of execution. Wolf-Rayet lives are measured in millions of years and sometimes much less. This is a blink of the eye compared to our sun's 10-billion-year life span. And because massive stars are already exceptions among star types, Wolf-Rayets are doubly rare: they are literally one star in a billion. Although their brightness makes them easy for telescopes to find, we know of only a few hundred of them in our entire galaxy.

Despite their rarity, these enigmatic stars have a history of entanglement with the most pressing astronomical questions of the day. As more observations of them arrive from powerful facilities such as the James Webb Space Telescope, this trend is repeating itself. Recently Wolf-Rayets have presented us with new questions about the physics that drives them, which may help solve big mysteries about the nature and fate of stars.

Peter Tuthill is an astronomer at the University of Sydney in Australia, where he researches astronomy and optics.

AN ENIGMA IS BORN

IN 1876, when French astronomers Charles Wolf and Georges Rayet first puzzled over three stars in the constellation of Cygnus, the science of spectroscopy—studying astronomical objects by spreading their light into its constituent colors—was in its infancy. Still, Wolf and Rayet had seen enough normal stars to know that something deeply bizarre was going on. Ordinary stars like the sun have spectra consisting of light from across the range of visible colors, imprinted with a scattering of narrow, fine dark lines that represent wavelengths being absorbed by the chemical elements in the stars. The new stars in Cygnus appeared to be something else entirely: they showed vibrant bands of bright color "more reminiscent of nebulae," the astronomers wrote, causing them to speculate that these stars might "mainly owe their brilliance to incandescent vapors."



Over the following decades, astronomers began to better understand the spectra of most stellar types, but Wolf-Rayets still languished as an incomprehensible oddity. They did occasionally ensnare scientists such as Ralph Copeland. In 1884 he made an expedition to

W. M. Keck Observatory/Peter Tuthill (*preceding page*); NASA/ESA/CSA/STScI/Lau et al., 2022 (*top left*); Shashank Dholakia/Peter Tuthill (*top left image processing*); Yinuo Han/Peter Tuthill (*top right*)

the shores of high-altitude Lake Titicaca in Peru, with astronomical equipment packed in by mule train. There he stumbled across the star γ Argus ("gamma Argus," now known as γ Velorum), whose "intensely bright line in the blue and the gorgeous group of three bright lines in the yellow and orange render its spectrum incomparably the most brilliant and striking in the whole heavens." Copeland was hooked: "The extraordinary beauty of this spectrum ... led me to devote a considerable part of my time to more or less systematic sweeps of the neighborhood of the Milky Way." He eventually netted another five similar stars. Although none were as spectacular as γ Velorum, this effort more than doubled the catalog of known Wolf-Rayets.

For half a century the Wolf-Rayet phenomenon remained "a door yet unopened and with a key so curious that we are not even sure how to insert it into the lock," as American astronomer Donald H. Menzel wrote in 1929. But during the 1930s various studies resulted in a gradual understanding of the physics behind the stars. Wolf and Rayet's comment about "incandescent vapors" was on the right track all along, but astronomers had been reluctant to dial up the physical conditions to the mind-boggling levels required.

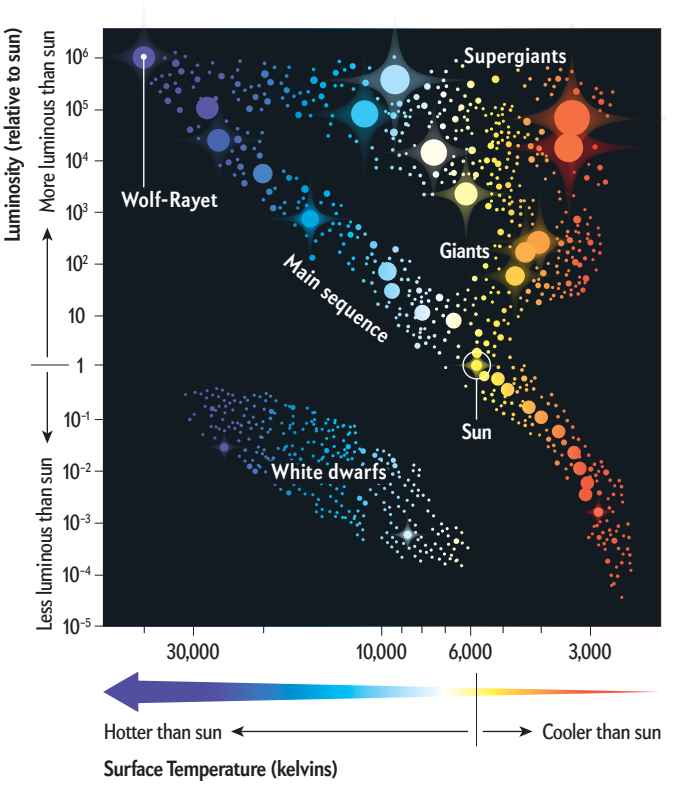
The searing temperatures in Wolf-Rayets fuel a radiation field at the stars' surface so powerful that the light itself becomes a force to be reckoned with. There is a fundamental upper bound to the luminosity of any celestial object beyond which "the radiation observed to be emitted … would blow up the star," Arthur Eddington wrote in an influential 1926 paper. Wolf-Rayets, it turns out, are so luminous that they flirt with this "Eddington limit," causing their surface layers to be continually driven off by the stars' incandescent glare. The key that opened Menzel's door turned out to be this strong stellar wind, streaming at several thousand kilometers per second—around 1 percent the speed of light. The phrase "solar hurricane" is sometimes used, but this comparison to our sun's solar wind does not remotely do it justice. Imagine the lightest discernible breath of air on a calm day compared to the force of a powerful water cannon. The divergence between our sun's solar wind and that of a Wolf-Rayet exceeds that ratio by a factor of more than 10,000.

Even a tiny handful of these overachievers can profoundly impact the ecosystem of an entire galaxy. Streaming winds carry energy, momentum and newly forged elements out into the voids between the stars, blowing bubbles, compressing clouds and heating gas. The most important contribution to the galactic balance from Wolf-Rayet stars is the least expected: stardust. Dust—tiny flakes of star stuff—plays all kinds of crucial roles in the grand cycle of matter in the galaxy, perhaps most of all by shielding and cooling the gas throughout, allowing it to condense to form new generations of stars. Yet astronomers have struggled to account for all the dust they see. In astronomy, dust is a little like snow: plentiful in calm conditions and cool climates. The last place to expect dust creation is somewhere bathed in the hot, harsh ultraviolet radiation surrounding a Wolf-Rayet.

The conundrum of how to form snowflakes in hell was resolved only with the discovery of the miraculous system named WR 140. In the 1980s a team led by Peredur Williams of the Royal Observatory Edinburgh found that dust produced by this star came in pulses spaced eight years apart. The discovery immediately linked the creation of dust to the eight-year period of a binary companion co-orbiting with the Wolf-Rayet. This companion was another luminous blue star on an elliptical orbit. In this binary system, astronomers realized, dust forms when the pair makes its closest approach. As the wind from the Wolf-Rayet collides with and entangles the wind of the massive companion, the two fight each other to a

Hertzsprung-Russell Diagram

This essential astronomical plot, called the Hertzsprung-Russell diagram, charts stars by temperature and brightness for comparison. Most stars, including our sun, spend the bulk of their lives somewhere on the "main sequence." Eventually stars swell into giants or supergiants as a prelude to their demise, which depends critically on their mass. The heavyweights explode as supernovae, leaving a black hole or neutron star remnant, whereas ordinary stars dwindle, leaving white dwarfs. Wolf-Rayets embody the extreme: hot, bright and with masses that doom them to a fiery end in a supernova.



Graphics by Sayo Studio

standstill. Here the cool, calm conditions are just right for dust to condense out of the gas. This colliding-wind dust mechanism requires that both stars launch powerful winds—a condition that can be met because massive stars often form along with similarly massive companions.

Unlike WR 140, many other Wolf-Rayets continuously pump out dust, apparently with no regard for the timing of their orbit. Figuring out why, and whether the continuous dust makers work differently from the clockwork dust-created-each-orbit variety, became a key question for my own research.

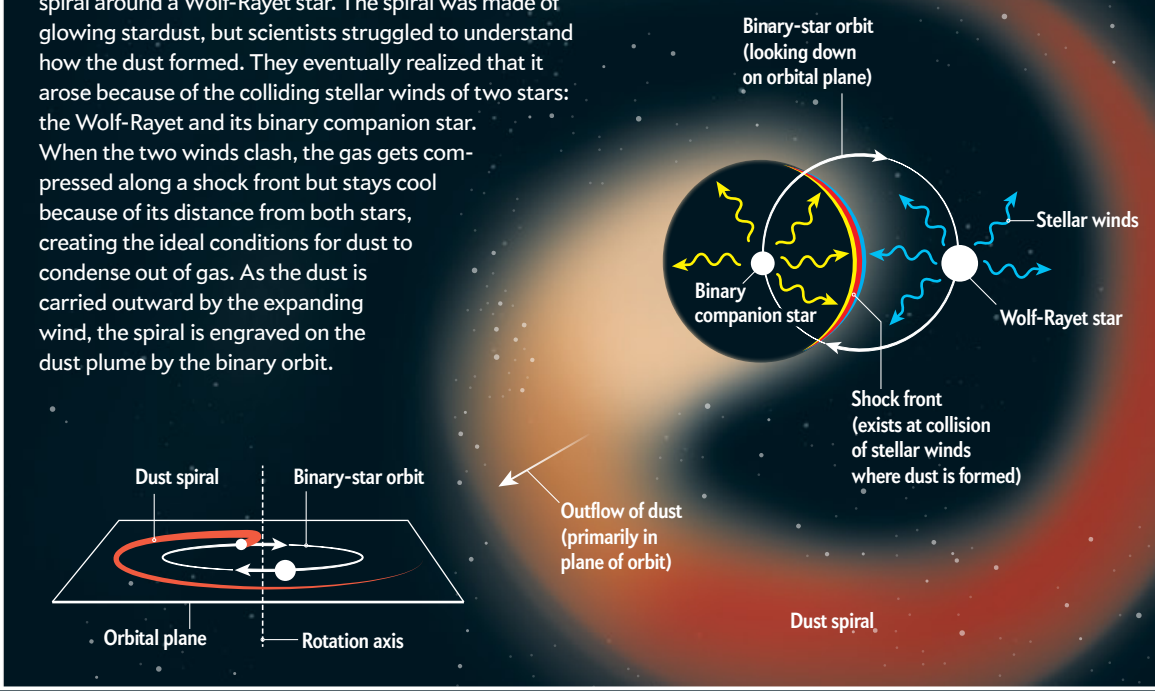
THE PINWHEELS

IN THE MID-1990S I was working in the group of Nobel Laureate Charles H. Townes in California with then student John D. Monnier. The giant Keck Telescopes in Hawaii had just opened for business. To understand Wolf-Rayet dust formation, however, we needed sharp images revealing a level of detail that was beyond the capability of even Keck's huge 10-meter mirrors. Today we could just switch on an adaptive optics system—now standard equipment that counteracts the shimmering of Earth's atmosphere. But in the 1990s technology able to image our Wolf-Rayet stars was tens of years and many millions of dollars in the future.

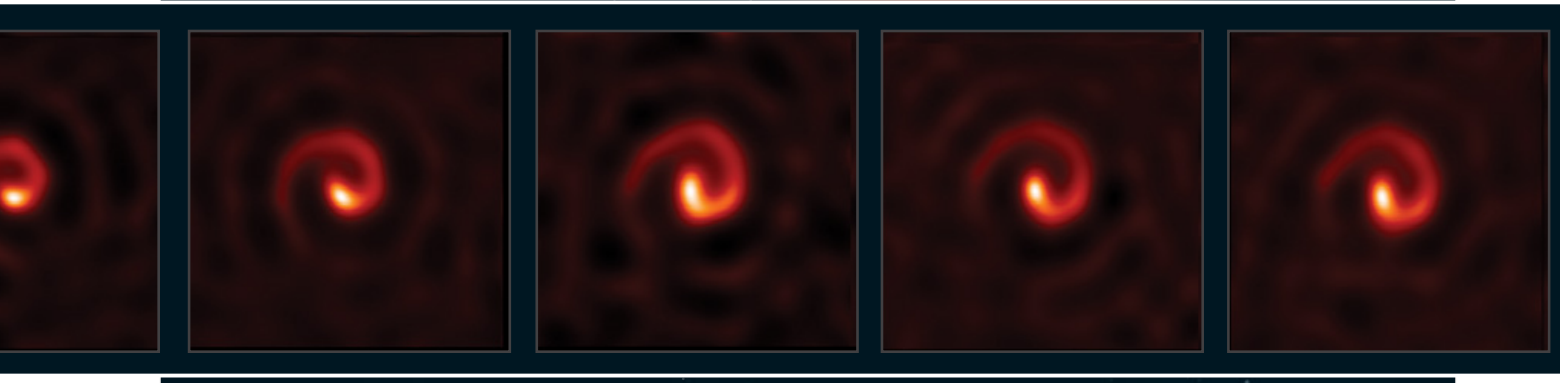
Necessity being the mother of invention, we had no option but to think laterally. We secured a large metal mask, about the size of a trash can lid with carefully arranged perforated holes, to one of the Keck telescopes. By blocking much of the starlight,

The Enigma of Dust Formation

Astronomers were puzzled when they first saw an elegant spiral around a Wolf-Rayet star. The spiral was made of glowing stardust, but scientists struggled to understand how the dust formed. They eventually realized that it arose because of the colliding stellar winds of two stars: the Wolf-Rayet and its binary companion star. When the two winds clash, the gas gets compressed along a shock front but stays cool because of its distance from both stars, creating the ideal conditions for dust to condense out of gas. As the dust is carried outward by the expanding wind, the spiral is engraved on the dust plume by the binary orbit.



W. M. Keck Observatory/Peter Tuthill (*model series*)



we transformed the primary mirror into an array of small collectors, allowing Keck to work much like modern radio telescopes that link many smaller antennas together. The gains in image fidelity exceeded our wildest dreams. The entire performance required climbing onto the telescope to swap out masks in the night while perched 15 meters above the observatory floor, which is something I am eternally surprised they ever let us get away with.

Forming images using this technique required significant computer processing, plus a lot of custom code. When we first beheld our most important Wolf-Rayet target, a star designated WR 104, on a computer monitor, it was a shimmering spiral that resembled a weirdly distorted Christmas bauble. I looked at John and groaned, "Never heard of any star shaped like a spiral. How did we get a bug in the code to produce that kind of error?" We went back and improved the code, but the spiral stayed put. It was not until a few months later, when data from a second visit to the Keck telescope produced another spiral, that we accepted reality. The new image was almost the same spiral shape as before but rotated by about 90 degrees. The spiral was real, and furthermore, we had a moving target on our hands.

Hindsight being what it is, I understand now that a spiral is exactly what we should have been looking for all along. What confused us was that dust needs dense, cool gas to form. A Wolf-Rayet can meet only one of these conditions at any given spot: close to the star the gas is dense but hot, whereas far away it is cool but too tenuous. This is where the binary pair comes in. When the winds from the two stars collide, the gas compresses far enough away from the stars for it to stay cool—conditions leading to a "dust nursery." Dust grains condense out of the gas along a bowl-shaped "shell" where the winds clash. As the stars orbit and their expanding winds sweep outward, the dust spirals out like the jet from a lawn sprinkler.

The result of all this physics manifests as a majestic spiral plume. To the eye of an astrophysicist, however, the beauty is deeper. These structures open a rare window into phenomena we could otherwise never hope to witness. It's as if nature writes its secrets in a script too tiny to see, but then the expanding wind inflates the text into a giant banner. Here were the properties of the winds, the stars that launched them and the parameters of their orbital dance, laid out for us to read. WR 104 became the prototype for a new class of nebulae that we christened "pinwheels." We soon found more systems, given names like WR 112 and WR 98a, that shared a common architecture, yet each was unique and distinctly beautiful.

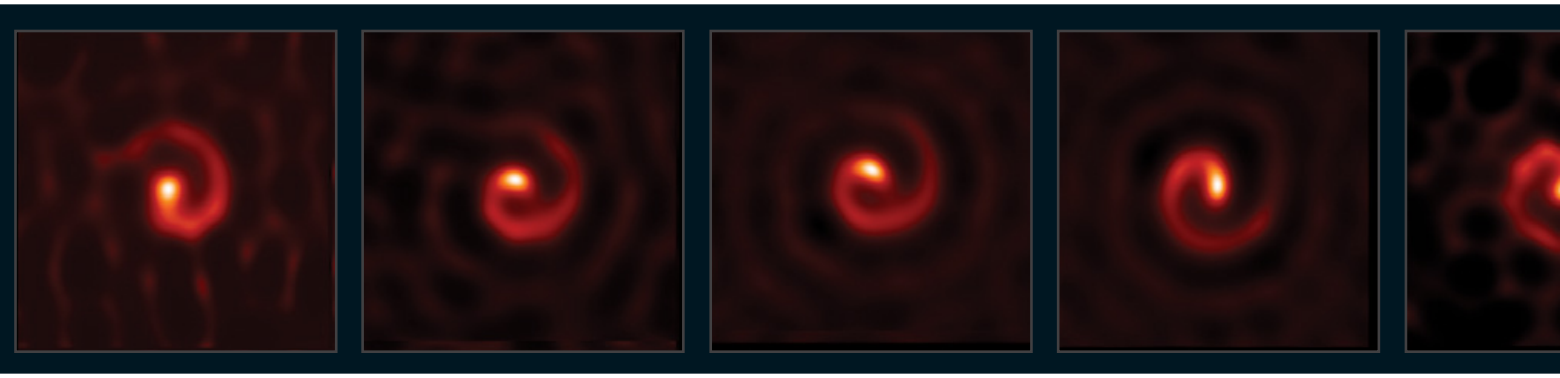
A NEW MYSTERY

IN THE YEARS SINCE, the pinwheels have continued to fascinate, beguile and confound us.

One ongoing puzzle began back in 1963, when the Partial Test Ban Treaty between the U.S. and the U.S.S.R. came into force, prompting America to launch the Vela satellites to monitor compliance by sensing gamma rays given off by nuclear tests. The sensors onboard these satellites began reporting events coming from above, not just below. These so-called gamma-ray bursts have since become one of the hottest topics in astronomy. A subtype of longer-duration bursts, which last more than two seconds, are thought to arise from the supernovae marking the deaths of Wolf-Rayet stars.

Not only are gamma-ray bursts intriguing, but over cosmic time they may even pose a safety risk. Typical supernovae can really affect only their immediate stellar neighborhood. This may not be true of gamma-ray-burst supernovae. Here the energy output is confined to a narrow and powerful beam, so with the right alignment they are visible at vast cosmic distances. Such an alignment for a nearby event may herald danger.

Speculative studies have suggested that events in Earth's fossil record, such as the Late Ordovician mass extinction, could have been caused by a gamma-ray-burst strike. The risk of such a cataclysm exists only when Earth is situated exactly along the line of the burst. For the first time our data allowed us to analyze the likely axis of a possible future burst from



A SERIES of images shows the motion of the dust spiral in the WR 104 system, which spins on the sky over the duration of one eight-month orbital cycle.

THE APEP triple-star system, seen in infrared (*left*), ejects a sculpted plume of hot dust around it. A computer simulation of the dust (*right*) can reproduce much of the complex structure in Apep's shell.

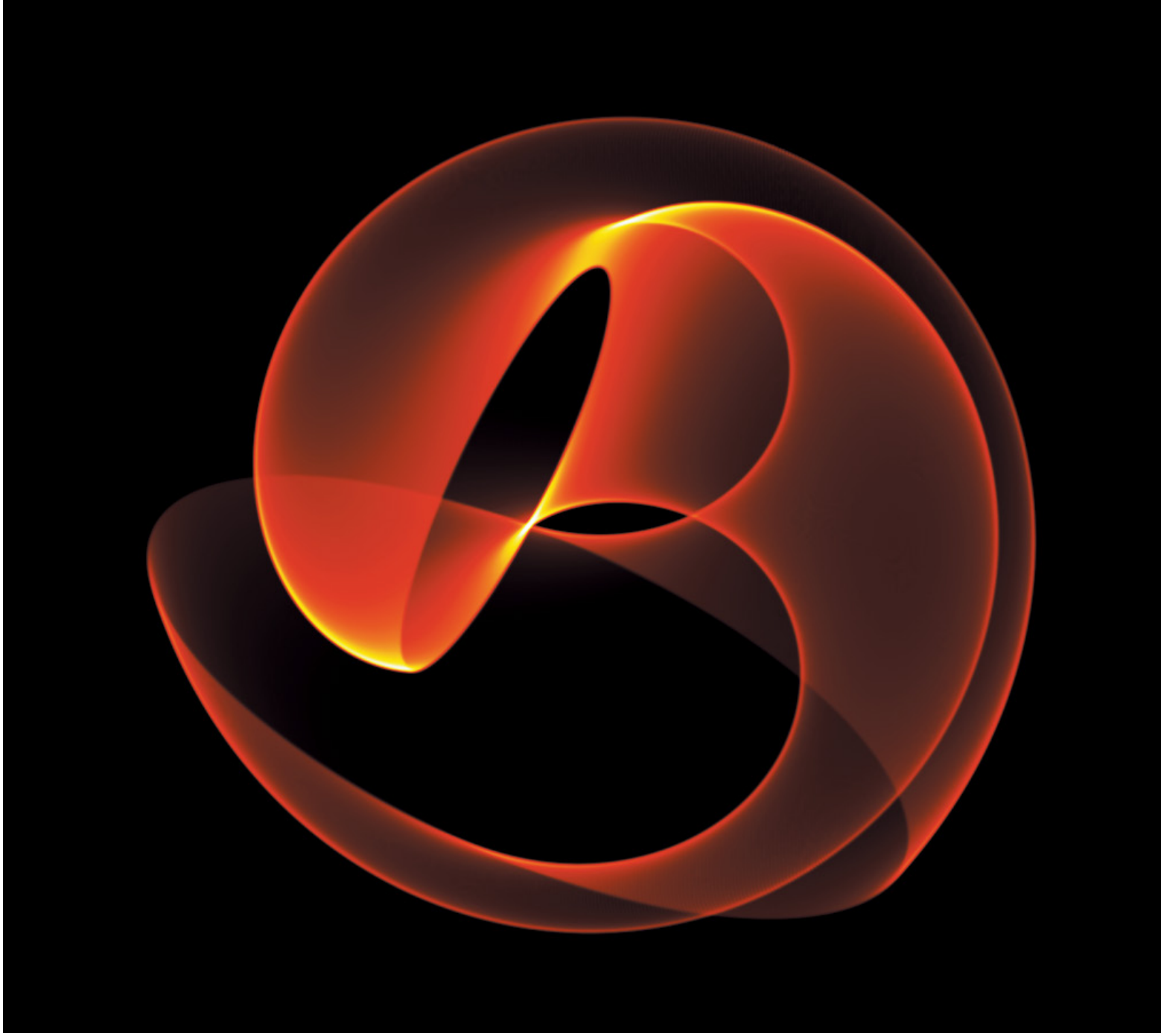
ESO/Callingham et al., 1999

our pinwheel Wolf-Rayets. Unfortunately, WR 104 might be pointing our way.

Yet the statistical threat posed by a future gamma-ray strike from WR 104 is truly minuscule: several very unlikely things would have to happen all in sequence, including the low-probability event WR 104 can host a gamma-ray burst (rather than a typical supernova) in the first place. When writing up our research, my colleagues and I weighed the vanishingly small but nonzero odds—and the fact humanity faces more serious threats from things such as climate change—and decided to include only a few short, carefully worded sentences on this possibility in our paper. Of course, these lines immediately went viral on the Internet. Soon I was in my department head's office, explaining how I'd become famous for 2012 end-of-the-world Mayan calendar conspiracy theories.

More recently, we've recovered spectacular new data on the pinwheels from observatories such as the James Webb Space Telescope, the likes of which Wolf and Rayet could hardly have imagined 150 years ago. Among the very first JWST images was a revelatory vision of an old friend, WR 140 (of the eight-year dust cycle mentioned earlier).

With the staggering leap in sensitivity from this new observatory, we can see shell after shell of dust—nearly 20 of them marching out into space, each an exquisitely sculpted replica nested within the older, more inflated one preceding it. My student Yinuo Han and I compared this observation with a previous computer model we'd built to describe only WR 140's single innermost dust shell. When we extrapolated



Yinuo Han/Peter Tuthill

out to see what 150 years of repeat shells might look like, our result almost perfectly mimicked the onion-layer image from JWST, showing the uncanny power of mathematics to echo the real world.

Perhaps the most exciting of the new discoveries has been the first confirmed twin Wolf-Rayet binary, a system called Apep, which my colleagues and I named after the mortal enemy of Egyptian sun god Ra. Images of the system evoke the mythology, suggesting a star embattled within a serpent's coils. Apep also offers a surprise. Our calculations clock the speed of the Wolf-Rayet's expanding gas wind, as well as the expansion rate of the dust. These two numbers should agree, and for all the other pinwheels, they do. In Apep, however, the dust streams out only one third as fast as the gas yet is caught in the teeth of the strongest howling gale known to stellar physics. It's like finding a feather adrift in a hurricane, somehow floating along at its own gentle pace. How does dust around Apep perform this magic trick? Nobody knows for sure.

Once again, Wolf-Rayets are humbling astronomers who think they understand how things work. And by the time we have the answer to this question, I'm sure these enigmatic stars will have given us still deeper mysteries. They have a history of mixing things up every time they make an appearance. SA

FROM OUR ARCHIVES

Explosions at the Edge. Anna Y. Q. Ho; December 2020.

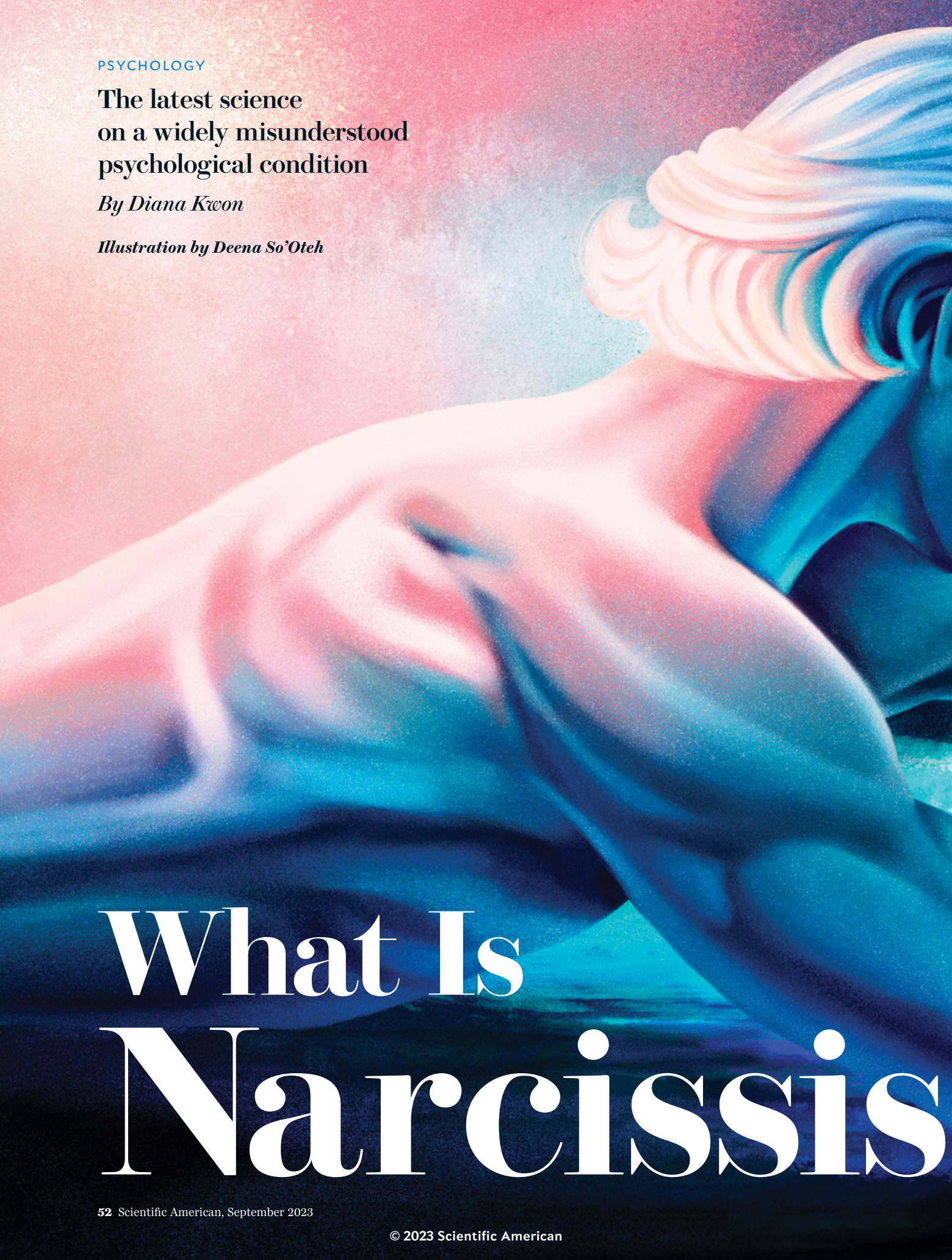
scientificamerican.com/magazine/sa

PSYCHOLOGY

The latest science on a widely misunderstood psychological condition

By Diana Kwon

Illustration by Deena So'Oteh



What Is Narcissis

m?

Diana Kwon is a freelance journalist who covers health and the life sciences. She is based in Berlin.

CAN YOU THINK OF A NARCISSIST? SOME PEOPLE MIGHT PICTURE DONALD TRUMP, PERHAPS, or Elon Musk, both of whom are often labeled as such on social media. Or maybe India's prime minister, Narendra Modi, who once wore a pinstripe suit with his own name woven in minute gold letters on each stripe over and over again.

But chances are you've encountered a narcissist, and they looked nothing like Trump, Musk or Modi. Up to 6 percent of the U.S. population, mostly men, is estimated to have had narcissistic personality disorder during some period of their lives. And the condition manifests in confoundingly different ways. People with narcissism "may be grandiose or self-loathing, extraverted or socially isolated, captains of industry or unable to maintain steady employment, model citizens or prone to antisocial activities," according to a review paper on diagnosing the disorder.

Clinicians note several dimensions on which narcissists vary. They may function extremely well, with successful careers and vibrant social lives, or very poorly. They may (or may not) have other disorders, ranging from depression to sociopathy. And although most people are familiar with the "grandiose" version of narcissism—as displayed by an arrogant and pompous person who craves attention—the disorder also comes in a "vulnerable" or "covert" form, where individuals suffer from internal distress and fluctuations in self-esteem. What these seeming opposites have in common is an extreme preoccupation with themselves.

Most psychologists who treat patients say that grandiosity and vulnerability coexist in the same individual, showing up in different situations. Among academic psychologists, however, many contend that these two traits do not always overlap. This debate has raged for decades without resolution, most likely because of a conundrum: vulnerability is almost always present in a therapist's office, but individuals high in grandiosity are unlikely to show up for treatment. Psychologist Mary Trump deduces, from family history and close observation, that her uncle, Donald Trump, meets the criteria for narcissistic as well as, probably, antisocial personality disorder, at the extreme end of which is sociopathy. But "coming up with an accurate and comprehensive diagnosis would require a full battery of psychological and neuropsychological tests that he'll never sit for," she notes in her book on the former president.

Now brain science is contributing to a better understanding of narcissism. It's unlikely to resolve the debate, but preliminary studies are coming down on the side of the clinicians: vulnerability indeed seems to be the hidden underside of grandiosity.

FANTASY OR REALITY?

TESSA, a 25-year-old who now lives in California, has sometimes felt on top of the world. "I would wake up every day and go to college believing I was going to be a famous singer and that my life was going to be fantastic," she recalls. "I thought I could just keep perfecting myself and that someday I would end up as this amazing person surrounded by this amazing life."

But she also hit severe emotional lows. One came when she realized that the fabulous life she imagined might never come to be. "It was one of the longest periods of depression I've ever gone through," Tessa tells me. "I became so bitter, and I'm still working through it right now."

That dissonance between fantasy and reality has spilled into her relationships. When speaking to other people, she often finds herself bored—and in romantic partnerships, especially, she feels disconnected from both her own and her partner's emotions. An ex-boyfriend, after breaking up, told her she'd been oblivious to the hurt she caused him by exploding in rage when he failed to meet her expectations. "I told him, 'Your suffering felt like a cry in the wind—I didn't know you were feeling that way' … all I could think about was how betrayed I felt," she says. It upset her to see him connect with other people; she reacted by degrading his friends and trying to stop him from meeting them. And she hated him admiring other people because it made her question whether he'd continue to see her as admirable.

Not being able to live the idealized versions of herself—which include visions of being surrounded by friends and fans who love and idolize her for her beauty and talent—leaves Tessa profoundly distressed. "Sometimes I simultaneously feel above everything, above life itself, and also like a piece of trash on the side of the road," she says. "I feel like I'm constantly trying to hide and cover things up. I'm constantly stressed and exhausted. I'm also constantly trying to build an inner self so I don't have to feel that way anymore." After her parents suggested therapy, Tessa was diagnosed with narcissistic personality disorder (NPD) in 2023.

What makes narcissism particularly complex is that it may not always be dysfunctional. "Being socially dominant, being achievement-striving and focused on improving one's own lot in

life by themselves are not all that problematic and tend to be valued by Western cultures," notes Aidan Wright, a psychologist at the University of Michigan.

Elsa Ronningstam, a clinical psychologist at McLean Hospital in Massachusetts, says the relatively functional variety of narcissism includes having, when things are going well, a positive view of oneself and a drive to preserve one's own well-being, while still being able to maintain close relationships with others and tolerate divergences from an idealized version of oneself. Then there is "pathological" narcissism, characterized by an inability to maintain a steady sense of self-esteem. Those with this condition protect an inflated view of themselves at the expense of others and—when that view is threatened—experience anger, shame, envy and other negative emotions. They can go about living relatively normal lives and act out only in certain situations. Narcissistic personality disorder is a subtype of pathological narcissism in which someone has persistent, long-term issues. It often occurs along with other conditions, such as depression, bipolar disorder, borderline personality or antisocial personality disorder.

THE 21ST-CENTURY NARCISSUS

IN THE ANCIENT GREEK TALE of Narcissus, a young hunter, admired for his unmatched beauty, spurns many who love and pursue him. Among them is Echo, an unfortunate nymph—who, after pulling a trick on one of the gods, has lost her ability to speak except for words already spoken by another. Though initially entranced by a voice that mirrored his own, Narcissus ultimately rejects Echo's embrace.

The god Nemesis then curses Narcissus, causing him to fall in love with his own reflection in a pool of water. Narcissus becomes hopelessly infatuated with his own image, which he believes to be another beautiful being, and becomes distraught when he finds it cannot reciprocate his affection. In some versions of the story, he wastes away before his own likeness, dying of thirst and starvation.

In the 1960s and 1970s psychoanalysts Heinz Kohut and Otto Kernberg sketched what's now known as the "mask model" of narcissism. It postulated that grandiose traits such as arrogance and assertiveness conceal feelings of insecurity and low self-esteem. The 1980 edition of the *Diagnostic and Statistical Manual of Mental Disorders* (*DSM*), the main reference used by clinicians in the U.S., reflected this insight by including vulnerable features in its definition of NPD, although it emphasized the grandiose ones. But some psychiatrists contended that the vulnerability criteria overlapped too much with those of other personality disorders. Borderline personality disorder (BPD), in particular, shares with NPD characteristics of vulnerability such as difficulty managing emotions, sensitivity to criticism, and unstable relationships. Subsequent versions of the *DSM* therefore placed even more weight on grandiose features—such as an exaggerated sense of self-importance, a preoccupation with fantasies of unlimited success and power, an excessive need for admiration and a lack of empathy.

In the early 2000s Aaron Pincus, a clinical psychologist at Pennsylvania State University, noticed that this focus on grandiosity did not accurately represent what he was seeing in narcissistic patients. "It was completely ignoring what typically drives patients to come to therapy, which is vulnerability and distress," Pincus says. "That got me on a mission to get us more calibrated in the science." In a 2008 review, Pincus and his colleagues discovered enormous variability in how mental health practitioners were conceptualizing NPD, with dozens of labels for the ways in which narcissism expressed itself. But there was also a common thread: descriptions of both grandiose and vulnerable ways in which the disorder showed up.

Since then, researchers have found that both dimensions of narcissism are linked to what psychologists call "antagonism," which includes selfishness, deceitfulness and callousness. But grandiosity is associated with being assertive and attention seeking, whereas vulnerability tends to involve neuroticism and suffering from anxiety, depression and self-consciousness. Vulnerable narcissism also more often goes along with self-harm (which can include hairpulling, cutting, burning and related behaviors that are also found in people with BPD) and risk of suicide than the grandiose form.

The two manifestations of narcissism are also linked to different kinds of problems in relationships. In grandiose states, people with NPD may be more vindictive and domineering toward others, whereas in vulnerable phases they may be more withdrawn and exploitable.

SELF-ESTEEM JUICE

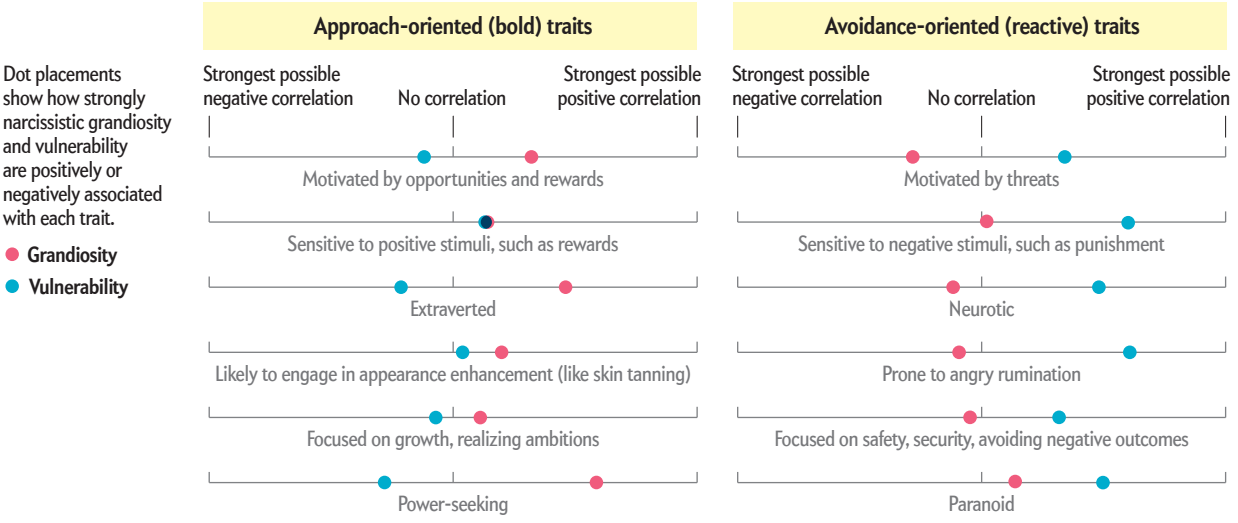
JACOB SKIDMORE, a 23-year-old with NPD who runs accounts as The Nameless Narcissist on several social media platforms, says he often flips from feeling grandiose to vulnerable, sometimes multiple times a day. If he's getting positive attention from others or achieves his goals, he experiences grandiose "highs" when he feels confident and secure. "It's almost a euphoric feeling," he says. But when these sources of ego boosts—something he refers to as "self-esteem juice"—dry up, he finds himself slipping into lows when an overwhelming feeling of shame might stop him from even leaving his home. "I'm afraid to go outside because I feel like the world is going to judge me or something, and it's painful," Skidmore says. "It feels like I'm being stabbed in the chest."

The desire to fill up on self-esteem has driven many of Skidmore's more grandiose behaviors—whether it was making himself the de facto leader of multiple social groups where he referred to himself as "the Emperor" and punished those who angered him or forging relationships purely for the sake of boosting his self-esteem. Skidmore hasn't always presented himself in grandiose ways: when he was younger, he was much more outwardly sensitive and insecure. "I remember looking in the mirror and thinking about how disgusting I was and how much I hated myself," he tells me.

Clinicians' evaluations, as well as studies in the wider population, support the idea that narcissists oscillate between these two states. In recent surveys, Wright and his graduate student Elizabeth Edershile asked hundreds of undergraduate students and community members to complete assessments that measured their levels of grandiosity and vulnerability multiple times a day over several days. They found that whereas vulnerability and grandiosity do not generally coexist in the same moment, people who are overall more grandiose also undergo periods of vulnerability—whereas those who are generally more vulnerable don't experience much grandiosity. Some studies suggest that the overlap may depend on the severity of the narcissism: clinical psychologist Emanuel Jauk of the Medical University of Graz in Austria and his colleagues found in surveys that vulnerability may be more likely to appear in highly grandiose individuals.

The Two Faces of Narcissism

People with narcissistic personality disorder vary widely in their levels of grandiosity (being arrogant and pompous) and vulnerability (being shy, insecure and hypersensitive). Further, these levels may vary with time and circumstances. An online survey of hundreds of people (*below*) by psychologists Zlatan Krizan and Anne D. Herlache, then at Iowa State University, revealed how narcissistic grandiosity and vulnerability differ on "approach-oriented" traits, characterized by boldness and arrogance, and "avoidance-oriented" traits, marked by vigilance and avoidance of threats to self-esteem.



To Diana Diamond, a clinical psychologist at the City University of New York, such findings suggest that the mask model is too simple. "The picture is much more complex—vulnerability and grandiosity exist in dynamic relation to each other, and they fluctuate according to what the individual is encountering in life, the stage of their own development."

But Josh Miller, a psychologist at the University of Georgia, and others entirely reject the idea that grandiose individuals are concealing a vulnerable side. Although grandiose people may sometimes feel vulnerable, that vulnerability isn't necessarily linked to insecurities, Miller argues. "I think they feel really angry because what they cherish more than anything is a sense of superiority and status—and when that's called into question, they're going to lash back," he adds. Psychologist Donald Lynam of Purdue University agrees: "I think people can be jerks for lots of reasons—they could simply think they're better than others or be asserting status or dominance—it's an entirely different motivation, and I think that motivation has been neglected."

These differences in perspective may arise because different types of psychologists are studying different populations. In a 2017 study, researchers surveyed 23 clinical psychologists and 22 social and/or personality psychologists (who do not work with patients) and found that although both groups viewed grandiosity as an essential aspect of narcissism, clinical psychologists were slightly more likely to view vulnerability as being at its core.

Most narcissists who seek help are generally more vulnerable, Miller notes: "These are wounded people who come in to seek treatment for their wounds." To him, that means clinics might not be the best place to study narcissism—at least not its grandiose aspect. It's "a little bit like trying to learn about a lion's behavior in a zoo," he says.

The unwillingness to seek therapy is especially true of "malignant narcissists," who, in addition to the usual characteristics, exhibit antisocial and psychopathic features such as lying chronically or enjoying inflicting pain or suffering on others.

Marianne (whose name has been changed for privacy) recalls her father, a brilliant scientist whom her own therapist deemed a malignant narcissist after reading the voluminous letters he'd sent over the years. (He never sought therapy.) It was "all about constant punishment," Marianne says. He implemented stringent rules, such as putting a strict time limit on how long their family of five children could use the bathroom during long road trips. If, by the time he'd filled the tank, everyone hadn't returned to the car, he'd leave. On one occasion, Marianne was abandoned at a gas station when she couldn't make it back on time. "There was [hardly] a day without that kind of drama—one person being isolated, punished, humiliated, being called out," she remembers. "If you cried, he'd say you're being histrionic. He didn't associate that crying with his actions; he thought it was performative."

Her father also pitted her siblings and their mother against one another to prevent them from forging close connections—and he constantly looked for flaws in those around him. Marianne recalls dinner parties at home where her father spent hours trying to pinpoint weaknesses among the other husbands and to hurt couples' opinions of each other. When Marianne brought home boyfriends, her father challenged them and tried to prove that he was superior. And despite being a dazzling academic who easily charmed people when they first met, he got fired time and time again

Source: "The Narcissism Spectrum Model: A Synthetic View of Narcissistic Personality," by Zlatan Krizan and Anne D. Herlache, in *Personality and Social Psychology Review*, Vol. 22; February 2018

Graphic by Amanda Montañez

because of conflicts at the universities where he worked. "It was all about one-upmanship," she says. "His impulse to destroy anything that was shiny, that was popular, that was loved—it overwhelmed everything else."

Malignant narcissists often pose the greatest challenge for therapists—and they may be particularly dangerous in leadership positions, Diamond notes. They can have deficient moral functioning while exerting an enormous amount of influence on followers. "I think this is something that's going on right now, with the rise of authoritarianism worldwide," she adds.

AN ADVERSE CHILDHOOD?

RESEARCH WITH IDENTICAL and nonidentical twins suggests that narcissism may be at least partially genetically heritable, but other studies indicate that dysfunctional parenting might also play a significant role. Grandiosity may derive from caregivers holding inflated views about their child's superiority, whereas vulnerability may originate in having a caregiver who was cold, neglectful, abusive or invalidating. Complicating matters, some studies find overvaluation also plays a role in vulnerable narcissism, whereas others fail to find a link between parenting and grandiosity. "Children who develop NPD may have felt seen and appreciated when they achieved or behaved in a certain way that satisfied a caregiver's expectations but ignored, dismissed or scolded when they failed to do so," Ronningstam summarizes in her guide to the disorder.

Skidmore attributes his own NPD to both genes and painful childhood experiences. "I've never met a narcissist who has not had trauma," he says. "People just use love as this carrot on a stick [that] they hang above your head, and they tell you to behave or they'll take it away. And so I have this mindset of, 'Well then, screw it! I don't need love. I can take admiration, achievements, my intelligence—you can't take those things away from me.'"

Many researchers nonetheless say a lot more work is needed to determine what role, if any, parenting plays. Miller points out that most research to date of grandiosity, in particular, has found small effects. Further, the work was done retrospectively—asking people to recall their past experiences—rather than prospectively to see how early life experiences affect outcomes.

There is another way to study what is going on with a narcissist, however: look inside. In a study published in 2015, researchers at the University of Michigan recruited 43 boys aged 16 or 17 and asked them to fill out the Narcissism Personality Inventory, a questionnaire that primarily measures grandiose traits. The teenagers then played Cyberball, a virtual ball-tossing game, while their brain activity was measured using functional magnetic resonance imaging (fMRI), a noninvasive neuroimaging method that enables researchers to observe the brain at work.

Cyberball tests how well people deal with social exclusion. Participants are told that they're playing with two other people, although they are actually playing with a computer. In some rounds, the virtual players include the human participant; in others, the virtual players begin by tossing the ball to everyone but later pass it just between themselves—cutting the participant out of the game.

The teenagers with higher levels of grandiose narcissism turned out to have greater activity in the so-called social pain network than those with lower scores. This network is a collection of brain regions—including parts of the insula and the anterior cingulate cortex—that prior studies had found were associated with distress in the face of social exclusion. Interestingly, the researchers did not find differences in the boys' self-reports of distress. In another revealing fMRI study, Jauk and his Graz colleagues found that men (but not women) with higher levels of grandiose narcissism showed more activity in parts of the anterior cingulate cortex associated with negative emotions and social pain when viewing images of themselves compared with images of close friends or strangers.

The bodies of narcissists bear evidence of elevated stress. Studies indicate that men with more narcissism have higher levels of the stress hormone cortisol than those with less narcissism. In a 2020 study, Royce Lee, a psychiatrist at the University of Chicago, and his colleagues reported that people with NPD—as well as those with BPD—have greater concentrations of molecules associated with oxidative stress (a stress response seen at the cellular level) in their blood.

Such findings suggest that "vulnerability is always there but maybe not always expressed," Jauk says. "And under particular circumstances, such as in the lab, you can observe signs of vulnerability at a physiological level, even if people say, 'I don't have vulnerability.'" He adds, however, that these studies are far from the last word on the matter: many of them have a small number of subjects, and some have reported contradicting findings. Follow-up studies, ideally with a larger number of individuals, are needed to validate their results. The neuroscience of narcissism "is incredibly interesting, but at the same time, I'm very hesitant to interpret any of these results," says Mitja Back, a psychologist at the University of Münster in Germany.

TOWARD TREATMENTS

TO DATE, THERE HAVE BEEN no randomized clinical trials for treatments specific for narcissistic personality disorder. Clinicians have, however, begun to adapt psychotherapies that have proved to be effective in other related conditions, such as borderline personality disorder. Treatments currently used include "mentalization," which aims to help individuals make sense of both their own and others' mental states, and "transference," which focuses on enhancing a person's ability to self-reflect, take the perspective of others and regulate their emotions. But there is still a dire need for effective treatments.

"People with pathological narcissism and narcissistic personality disorder have a reputation of not changing or dropping off from treatment," Ronningstam says. "Instead of blaming that on them, the clinicians and researchers need to really further develop strategies that can be adjusted to the individual difference—and at the same time to focus on and promote change."

Since discovering she has NPD, Tessa has started a YouTube channel called SpiritNarc where she posts videos about her experiences and perspectives on narcissism. "I really want the world to understand [narcissism]," she says. "I'm so sick of the narrative that's going around—people see the outside behavior and say, 'This means these people are awful.'" What these people don't see, she adds, is the suffering that lies below the surface. SA

FROM OUR ARCHIVES

The Long Shadow of Trauma. Diana Kwon; January 2022.

scientificamerican.com/magazine/sa

COMPUTING

An AI Mystery

Researchers are struggling to understand how artificial-intelligence models know things no one told them

By George Musser

Illustration by Chris Gash

NO ONE YET KNOWS HOW CHATGPT AND ITS ARTIFICIAL-INTELLIGENCE cousins will transform the world, and one reason is that no one really knows what goes on inside them. Some of these systems' abilities go far beyond what they were trained to do—and even their inventors are baffled as to why. A growing number of tests suggest these AI systems develop internal models of the real world, much as our own brain does, although the machines' technique is different.

"Everything we want to do with them in order to make them better or safer or anything like that seems to me like a ridiculous thing to ask ourselves to do if we don't understand how they work," says Ellie Pavlick of Brown University, one of the researchers working to fill that explanatory void.

At one level, she and her colleagues understand GPT (short for "generative pre-trained transformer") and other large language models, or LLMs, perfectly well. The models rely on a machine-learning system called a neural network. Such networks have a structure modeled loosely after the connected neurons of the human brain. The code for these programs is relatively simple and fills just a few screens. It sets up an autocorrection algorithm, which chooses the most likely word to complete a passage based on laborious statistical analysis of hundreds of gigabytes of Internet text. Additional training ensures the system will present its results in the form of dialogue. In this sense, all it does is regurgitate what it learned—it is a "stochastic parrot," in the words

of Emily Bender, a linguist at the University of Washington. (Not to dishonor the late Alex, an African Grey Parrot who understood concepts such as color, shape and "bread" and used corresponding words intentionally.) But LLMs have also managed to ace the bar exam, write a sonnet about the Higgs boson and make an attempt to break up their users' marriage. Few had expected a fairly straightforward autocorrection algorithm to acquire such broad abilities.

That GPT and other AI systems perform tasks they were not trained to do, giving them "emergent abilities," has surprised even researchers who have been generally skeptical about the hype over LLMs. "I don't know how they're doing it or if they could do it more generally the way humans do—but they've challenged my views," says Melanie Mitchell, an AI researcher at the Santa Fe Institute.

"It is certainly much more than a stochastic parrot, and it certainly builds some representation of the world—although I do not think that it is quite like how humans build an internal world model," says Yoshua Bengio, an AI researcher at the University of Montreal.

At a conference at New York University in March, philosopher Raphaël Millière of Columbia University offered yet another jaw-dropping example of what LLMs can do. The models had already demonstrated the ability to write computer code, which is impressive but not too surprising because there is so much code out there on the Internet to mimic. Millière went a step further and showed that GPT can execute code, too, however. The philosopher typed in a program to calculate the 83rd number in the Fibonacci sequence. "It's multistep reasoning of a very high degree," he says. And the bot nailed it. When Millière asked directly for the 83rd Fibonacci number, however, GPT got it wrong, which suggests the system wasn't just parroting the Internet. Rather it was performing its own calculations to reach the correct answer.

Although an LLM runs on a computer, it is not itself a computer. It lacks essential computational elements, such as working memory. In a tacit acknowledgment that GPT on its own should not be able to run code, its inventor, tech company OpenAI, has since introduced a specialized plug-in—a tool ChatGPT can use when answering a query—that allows it to do so. But that plug-in was not used in Millière's demonstration. Instead he hypothesizes that the machine improvised a memory by harnessing its mechanisms for interpreting words according to their context—a situation similar to how nature repurposes existing capacities for new functions.

This impromptu ability demonstrates that LLMs develop an internal complexity that goes well beyond a shallow statistical analysis. Researchers are finding that these systems seem to achieve genuine understanding of what they have learned. In one study presented in May at the International Conference on Learning Representations, doctoral student Kenneth Li of Harvard University and his AI researcher colleagues—Aspen K. Hopkins of the Massachusetts Institute of Technology; David Bau of Northeastern University; and Fernanda Viégas, Hanspeter Pfister and Martin Wattenberg, all at Harvard—spun up their own smaller copy of the GPT neural network so they could study its inner workings. They trained it on millions of matches of the board game Othello by feeding in long sequences of moves in text form. Their model became a nearly perfect player.

To study how the neural network encoded information, they adopted a technique that Bengio and Guillaume Alain, also at the University of Montreal, devised in 2016. They created a miniature "probe" network to analyze the main network layer by layer. Li compares this approach to neuroscience methods. "This is similar to when we put an electrical probe into the human brain," he says. In the case of the AI, the probe showed that its "neural activity" matched the representation of an Othello game board, albeit in a convoluted form. To confirm this, the researchers ran the probe in reverse to implant information into the network—for instance, flipping one of the game's black marker pieces to a white one. "Basically we hack into the brain of these language models," Li says. The network adjusted its moves accordingly. The researchers concluded that it was playing Othello roughly like a human: by keeping a game board in its "mind's eye" and using this model to evaluate moves. Li says he thinks the system learns this skill because it is the most parsimonious description of its training data. "If you are given a whole lot of game scripts, trying to figure out the rule behind it is the best way to compress," he adds.

This ability to infer the structure of the outside world is not limited to simple game-playing moves; it also shows up in dialogue. Belinda Li (no relation to Kenneth Li), Maxwell Nye and Jacob Andreas, all at M.I.T., studied networks that played a text-based adventure game. They fed in sentences such as "The key is in the treasure chest," followed by "You take the key." Using a probe, they found that the networks encoded within themselves variables corresponding to "chest" and "you," each with the property of possessing a key or not, and updated these variables sentence by sentence. The system had no independent way of knowing what a box or key is, yet it picked up the concepts it needed for this task. "There is some representation of the state hidden inside of the model," Belinda Li says.

Researchers marvel at how much LLMs are able to learn from text. For example, Pavlick and her then Ph.D. student Roma Patel found that these networks absorb color descriptions from Internet text and construct internal representations of color. When they see the word "red," they process it not just as an abstract symbol but as a concept that has certain relations to maroon, crimson, fuchsia, rust, and so on. Demonstrating this was somewhat tricky. Instead of inserting a probe into a network, the researchers studied its response to a series of text prompts. To check whether it was merely echoing color relations from online references, they tried misdirecting the system by telling it that red is in fact green—like the old philosophical thought experiment in which one person's red is

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another person's green. Rather than parroting back an incorrect answer, the system's color evaluations changed appropriately to maintain the correct relations.

Picking up on the idea that to perform its autocorrection function the system seeks the underlying logic of its training data, machine-learning researcher Sébastien Bubeck of Microsoft Research suggests that the wider the range of the data, the more general the rules the system will discover. "Maybe we're seeing such a huge jump because we have reached a diversity of data, which is large enough that the only underlying principle to all of it is that intelligent beings produced them," he says. "And so the only way to explain all of the data is [for the model] to become intelligent."

In addition to extracting the underlying meaning of language, LLMs can learn on the fly. In the AI field, the term "learning" is usually reserved for the computationally intensive process in which developers expose the neural network to gigabytes of data and tweak its internal connections. By the time you type a query into ChatGPT, the network should be fixed; unlike humans, it should not continue to learn. So it came as a surprise that LLMs do, in fact, learn from their users' prompts—an ability known as in-context learning. "It's a different sort of learning that wasn't really understood to exist before," says Ben Goertzel, founder of AI company SingularityNET.

One example of how an LLM learns comes from the way humans interact with chatbots such as ChatGPT. You can give the system examples of how you want it to respond, and it will obey. Its outputs are determined by the last several thousand words it has seen. What it does, given those words, is prescribed by its fixed internal connections—but the word sequence nonetheless offers some adaptability. Entire websites are devoted to "jailbreak" prompts that overcome the system's "guardrails"—restrictions that stop the system from telling users how to make a pipe bomb, for example—typically by directing the model to pretend to be a system without guardrails. Some people use jailbreaking for sketchy purposes, yet others deploy it to elicit more creative answers. "It will answer scientific questions, I would say, better" than if you just ask it directly, without the special jailbreak prompt, says William Hahn, co-director of the Machine Perception and Cognitive Robotics Laboratory at Florida Atlantic University. "It's better at scholarship."

Another type of in-context learning happens via "chain of thought" prompting, which means asking the network to spell out each step of its reasoning—a tactic that makes it do better at logic or arithmetic problems requiring multiple steps. (But one thing that made Millière's example so surprising is that the network found the Fibonacci number without any such coaching.)

In 2022 a team at Google Research and the Swiss Federal Institute of Technology in Zurich—Johannes von Oswald, Eyvind Niklasson, Ettore Randazzo, João Sacramento, Alexander Mordvintsev, Andrey Zhmoginov and Max Vladymyrov—showed that in-context learning follows the same basic computational procedure as standard learning, known as gradient descent. This procedure was not programmed; the system discovered it without help. "It would need to be a learned skill," says Blaise Agüera y Arcas, a vice president at Google Research. In fact, he thinks LLMs may have other latent abilities that no one has discovered yet. "Every time we test for a new ability that we can quantify, we find it," he says.

Although LLMs have enough blind spots not to qualify as artificial general intelligence, or AGI—the term for a machine that attains the resourcefulness of animal brains—these emergent abilities suggest to some researchers that tech companies are closer to AGI than even optimists had guessed. "They're indirect evidence that we are probably not that far off from AGI," Goertzel said in March at a conference on deep learning at Florida Atlantic University. OpenAI's plug-ins have given ChatGPT a modular architecture a little like that of the human brain. "Combining GPT-4 [the latest version of the LLM that powers ChatGPT] with various plug-ins might be a route toward a humanlike specialization of function," says M.I.T. researcher Anna Ivanova.

ChatGPT was playing Othello roughly like a human: by keeping a game board in its "mind's eye" and using this model to evaluate its moves.

At the same time, though, researchers worry the window may be closing on their ability to study these systems. OpenAI has not divulged the details of how it designed and trained GPT-4, in part because it is locked in competition with Google and other companies—not to mention other countries. "Probably there's going to be less open research from industry, and things are going to be more siloed and organized around building products," says Dan Roberts, a theoretical physicist at M.I.T., who applies the techniques of his profession to understanding AI.

And this lack of transparency does not just harm researchers, says Mitchell of the Santa Fe Institute. It also hinders efforts to understand the social impacts of the rush to adopt AI technology. "Transparency about these models is the most important thing to ensure safety." SA

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AI Writes about Itself. Almira Osmanovic Thunström; September 2022.

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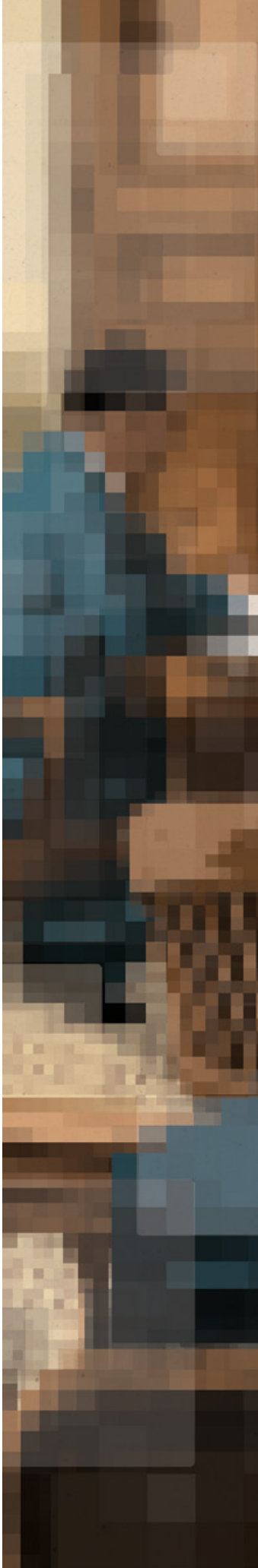
COGNITIVE SCIENCE

The Dementia Defense

When criminal behavior overlaps with degenerative cognitive disease, the justice system often falters

By Jessica Wapner

Illustrations by Mark Smith



Jessica Wapner is a science journalist. She is author of *Wall Disease* (2020) and *The Philadelphia Chromosome* (2014), both published by The Experiment. Wapner lives in upstate New York.

DAVID ROTHMAN DELIVERED HIS LAST BABY IN 2003 AND SHUT DOWN HIS OBSTETRICS practice at the age of 62. A couple of years later he became the medical director of a newly opened clinic, called Medcore, that specialized in HIV care.

The clinic was in a nondescript office building in Miami, out near the airport. Reyes Cruz, who was diagnosed with HIV in 1994, first visited in the summer of 2005. He told Rothman that he had stomach cramps, bleeding gums and diarrhea. Rothman looked inside his mouth, took his pulse and pressed on his stomach. Cruz had his blood drawn. Afterward, a phlebotomist asked him to sign a form verifying his visit, then handed him $600 in cash. Cruz visited Medcore regularly for nearly a year, receiving $600 each time, sometimes in the clinic's bathroom, sometimes in the parking lot.

Cruz later testified that he had lied about his ailments. The clinic was a scam. The owners bribed people with HIV to serve as pretend patients. Rothman signed Medicare claim forms for HIV drugs that were never purchased by the clinic nor provided to the patients. Over about two years Medcore billed Medicare for $4,040,895 in fake expenses. Bank records indicate that Rothman received at least $600,000 from Medcore and other similar schemes that he was allegedly involved in.

FBI agents arrested Rothman and seven other people in October 2008. (By this time, he'd relinquished his medical license for a different reason: the state's Department of Health accused him of prescribing Viagra based solely on online questionnaires.) Rothman was charged with health-care fraud and health-care fraud conspiracy. He faced up to 20 years in prison. Four of the indicted defendants pleaded guilty, and four, including Rothman, chose to go to trial.

Shortly before the jury was set to assemble, Rothman's attorney filed a motion stating that his client was incompetent to stand trial. Five months before his arrest, Rothman had been diagnosed with Alzheimer's disease. The legal process that followed would last 11 years—a costly demonstration of just how unprepared the criminal justice system is to handle people with dementia.

NEARLY 10 PERCENT OF U.S. ADULTS AGE 65 AND OVER HAVE some form of dementia, and another 22 percent have mild cognitive impairment. Alzheimer's, the most common type, has symptoms we tend to associate with cognitive decline in the elderly—wandering, disorientation, memory loss, struggling to find the right word. In frontotemporal dementia, a person may become impulsive or lose their ability to sympathize. Lewy body dementia can cause tremors and change sleep patterns. A person with vascular dementia may hallucinate. Symptoms often overlap, which can make diagnosis tricky.

Some forms of dementia can trigger behaviors that society classifies as criminal. It's not that these conditions create an *intention* to violate the law—most dementia-related violations are not what neurologists call "instrumental behaviors," which are calculated in advance and executed according to a plan. Rather the radical changes in a person's behavior and demeanor can erase their sense of social norms. They steal. They grope. They shout abusive language at fellow customers in the grocery store. Stacey Wood, a professor of psychology at Scripps College, recalled a patient who began hugging customers at a convenience store and didn't stop until the manager called the police. "Mostly we're talking about impulse-control problems," says Wood, who has provided expert testimony in many cases involving defendants and victims with dementia. "They just have terrible judgment."

These radical changes in a person's cognition and behavior tend to come from a loss of awareness about the world. Some people lose what psychologists call theory of mind—that is, the ability to comprehend that other people have minds and mental states just like they do. People with dementia can also lose self-conscious emotions or "where you see yourself through others," says Mario Mendez, director of the Behavioral Neurology Program at the David Geffen School of Medicine at U.C.L.A. When that capacity evaporates, a person no longer feels shame or guilt about breaking with acceptable social patterns. The loss of these capacities may help explain the most common crimes among Alzheimer's patients—public urination, theft, traffic violations, sexual advances and trespassing.

Not everyone with dementia steals or runs red lights, of course, but it appears that people with this diagnosis are more susceptible to criminal behavior. It's difficult to determine just how often the police are called to intervene in dementia-driven behavior, but one way to look at it is through FBI data. More than 100,000 people older than 65 were arrested in 2019, a number that represents about 0.18 percent of *all* people older than 65 in the U.S. For comparison, 8.5 percent of the patients seen at the University of California, San Francisco, Memory and Aging Center between 1999 and 2012 committed crimes after receiving their diagnosis.

Most dementia-related transgressions do not land the guilty party in prison or even in front of a jury. Guilt has two properties: that a person committed the crime and that they intended to do so. The latter, known as mens rea, is usually missing when dementia patients violate the law. Charges are typically dropped once the police, the victim or the prosecuting attorney realizes that a defendant is not of sound mind.

Still, a portion of older individuals who commit crimes because a neurodegenerative disorder has warped their sense of acceptable behavior do end up incarcerated. Mendez recalled a patient of his who was arrested for touching a child in a way that would have been acceptable ("something like patting on the head," he explained) if the patient had known the child. Another patient went to jail for taking something trivial from a store. In 2021 a 67-year-old man with Alzheimer's spent several months in an Oklahoma jail for allegedly stealing a car, even though it was clear to the arresting officer that the man didn't understand why he was being pulled over and was confused about where he was.

Jalayne Arias, who studies health policy and behavioral sciences at the School of Public Health at Georgia State University, wanted to know how attorneys handle people who are arrested for offenses stemming from their dementia, including how they discern whether the disease is what led to the criminal activity. She interviewed 15 attorneys between 2020 and 2021, and their responses (which will be published soon in the *American Journal of Law and Medicine*) indicated to Arias that the criminal justice system lacks a consistent approach for screening older offenders for dementia.

If the police realize that the suspect they've just arrested has Alzheimer's, they have nowhere to bring that person besides the nearest precinct or emergency room. The attorneys Arias interviewed recognized that jails and prisons aren't clinically appropriate, because simply being in unfamiliar places and situations can be harmful to people with dementia. Offenders without caregivers may be best served by placement at a long-term care facility, but often they cannot afford it. And the criminal record they now have may make them ineligible anyway. "Our legal system as a whole just really hasn't wrapped its head around this particular issue," Arias says.

In general, people with Alzheimer's are known to be victims of scams, not the perpetrators. They don't start fake clinics to defraud Medicare.

Defendants with psychiatric illnesses may plead not guilty by reason of insanity, or they may insist they didn't have conscious control over themselves—they were sleepwalking when they stole a candy bar, for example. There are no such protections for elderly people with cognitive disease.

In general, people with Alzheimer's are known to be victims of scams, not the perpetrators. They don't start fake clinics to defraud Medicare. A crime like that "is not something that you can easily attribute to brain disease," Mendez says.

THE FBI CONTACTED ROTHMAN ABOUT HIS WORK WITH Medcore in December of 2005. Later that month, according to his daughter Raquel Rothman, he testified before a grand jury. Raquel found out about the testimony only because her father showed up at her sister's house afterward wearing a suit, which was odd for him. When her sister asked their dad why he was so dressed up, he nonchalantly told her where he'd been. Raquel, an attorney, was alarmed to hear he'd testified without a lawyer present. (The details of grand jury hearings are publicly unavailable.)

Raquel immediately contacted her dad's former fraternity brother, Joel Hirschhorn, A 1995 *New Yorker* story described Hirschhorn as a white-collar defense attorney who had formerly defended drug dealers in 1980s Miami. The two men had run into each other occasionally since college, but it had been

many years since the last time. When Hirschhorn met with Rothman, he seemed "disheveled and depressed," nothing like the sharp student he'd remembered. Hirschhorn says he gave Rothman the name of a psychiatrist. That doctor referred Rothman to a neuropsychologist, who diagnosed Rothman with mild cognitive impairment in March 2007 and sent him to a neurologist for further testing. In May 2008, more than two years after the first doctor's appointment and two months before the indictment, the neurologist diagnosed Rothman with Alzheimer's.

The Sixth Amendment of the U.S. Constitution entitles every criminal defendant to a fair trial. That includes ensuring that a defendant is fully capable of understanding the proceedings. The cognitive demands of a trial are substantial: understanding the evidence; weighing the benefits and risks of taking the stand; considering a plea deal; remaining alert and focused while court is in session; communicating meaningfully with an attorney. When a person's ability to participate in their defense is in question, their attorney can request a competency evaluation, which is essentially an investigation of the defendant's mind.

The modern rules surrounding a defendant's competency stem from *Dusky v. United States,* a 1958 case in which a 33-year-old man named Milton Dusky was accused of kidnapping a minor. Dusky had schizophrenia, but the court ruled him fit to handle the criminal justice process. He was found guilty and sentenced to 45 years in prison. After an initial appeal failed, the Supreme Court reversed the decision in 1960, leading to the "Dusky standard" of competency: that defendants understand the charges against them and the possible penalties and that they can assist in the preparation of their defense.

Dusky applies to all neurological conditions. The law does not differentiate between mental illnesses that can be ameliorated with medication, such as schizophrenia, bipolar and clinical depression, and those that are incurable, such as dementia.

To determine whether a defendant meets the Dusky standards of competency, the court appoints an expert to conduct a forensic evaluation. These investigations use the same tools that a doctor would use to check for cognitive impairment. First come biological tests to rule out other causes of dementia, such as vitamin deficiencies, HIV and urinary tract infections, all of which are curable, which means the comprehension issues are resolvable. The evaluator may also order an imaging scan to check for signs of erosion inside the brain.

A battery of cognitive tests for dementia includes questions that check memory, recognition, language recall, executive function, and other brain skills. A patient might be asked to name the city and state they're in or to draw a clock with the hands showing a specific time. The evaluator may test a person's sense of right and wrong by asking them to explain the meaning of a proverb. In a clinical setting, the goal is to make a diagnosis. In a forensic setting, the goal is to determine whether the defendant can plan a legal strategy, understand courtroom procedure and decorum, comprehend the charges against them,

challenge witnesses and feel invested in the outcome.

Competency evaluations are rigorous because they connect to a fundamental tenet of the U.S. justice system: that people must be held accountable for violating the law. People with early-stage Alzheimer's are no exception. The ability to consult with one's lawyer does not mean remembering every relevant fact; even defendants with amnesia have been ruled competent. "Having mild cognitive impairment or an early dementia, in most legal settings, would be insufficient to obviate responsibility for a crime," says Tom Wisniewski, who directs N.Y.U. Langone's Center for Memory Evaluation and Treatment.

Cognitive tests to determine competency to stand trial provide only a snapshot of the moment at which they're given, which doesn't capture the fluctuations that dementia can cycle through over a week or even a single day. They can miss the loss of feelings or inhibitions. Also, some people may exaggerate symptoms to stay out of prison. Forensic and clinical evaluators therefore also interview family and friends. Only people who know the defendant's history can provide insights about behavioral changes over time. "The cognitive assessment of the patient is critically dependent on having an informant," Wisniewski says.

When Hirschhorn requested a competency evaluation for Rothman, the judge appointed a local neuropsychologist, Enrique Suarez, to conduct it. Suarez gave Rothman four cognitive tests over two days in February 2009 and noticed some peculiarities that didn't match a typical Alzheimer's patient. For example, Rothman's recall was better than his recognition. Rothman got an average score on a word-list recall test but scored far below average when he was asked whether he recognized something he'd been shown a few minutes earlier. And in a test in which Rothman had to choose which of two words he'd seen before, he did much poorer than someone at his stage of Alzheimer's typically does. His IQ score was 85 (90 to 109 is considered average), which struck Suarez as unlikely for someone with Rothman's educational and professional background. It was also 20 points lower than he had scored on the same test administered by his regular neuropsychologist at around the same time. Suarez thought it was strange when Rothman disclosed that he'd been suffering from auditory hallucinations—hearing things—for the past 15 years because Rothman had never mentioned this to any of his doctors.

For the family component, Suarez interviewed only Raquel. The court records contain no explanation of why he did not interview Rothman's wife of 17 years, Amanda Rothman. It also omits the fact that Rothman and Raquel had been all but estranged since she was a teenager, so she would not necessarily know how her father had changed.

The competency hearing before the judge came a week after Suarez's evaluation. All the clinicians who had examined Rothman since 2006 gave the judge their test results, imaging reports and conclusions about whether Rothman was fit to stand trial. Everyone said Rothman was incompetent, except for Suarez, who insisted that Rothman didn't even have dementia. Rather Rothman's test scores were so inconsistent and, at times, so low that they could point to only one conclusion: Rothman was malingering, Suarez said. He was faking it.

UNITED STATES V. GIGANTE IS PROBABLY THE MOST FAMOUS case involving malingering. Gigante faked a mental illness for decades to cover up his role as the head of the Genovese crime family, mumbling to himself as he walked the city streets in tattered clothes. He used that act to delay his conviction for years after he was arrested in 1990. A judge finally ruled him competent to stand trial, leading to a guilty verdict in 1997. (Gigante only admitted the ruse a couple years before he died in prison.)

Clinically, it's impossible to know when dementia first starts taking root in a person's brain or when it begins chipping away at a person's empathy or inhibitions.

Detecting that someone is malingering is not an exact science. Evaluators often get it wrong. Gigante-style fakes are rare. "People can be mentally ill and malingering; they can be demented and exaggerate," says Rory Houghtalen, a forensic psychiatrist who consults on criminal legal cases in New York State. "You gotta be real careful about throwing the m-word around."

Still, the judge found Suarez's testimony to be the most convincing. She didn't declare that Rothman was pretending, but she questioned why Rothman had not sought treatment until he discovered he was under investigation in 2005. She concluded that Rothman was suffering from "a mental disease or defect" but not one that compromised his cognition enough to render him legally incompetent. He had explained his innocence to his doctors; surely he could do the same before a jury. Rothman, she ruled, was competent to proceed to trial.

The judge would not permit expert witnesses to testify that Rothman's Alzheimer's diagnosis contributed to his participation in the Medcore scheme. Clinically, it's impossible to know when dementia first starts taking root in a person's brain or when it begins chipping away at a person's empathy or inhibitions. The legal system couldn't retroactively determine his state of

mind when he was signing fraudulent Medicare forms.

The proceedings lasted two weeks in March 2009. Hirschhorn did not try to blame Rothman's criminal actions on Alzheimer's disease, but he did argue that issues with executive functioning muddled Rothman's ability to see Medcore for what it was. In his opening statement, he referred to Rothman as "a doddering old fool" who had "developed extremely poor judgment." Later, he argued to the jury that Rothman was a devoted physician who was trying to take proper care of his HIV patients. He was a good doctor who had been taken advantage of by bad people.

The jury found Rothman guilty on all five counts against him, and the prosecution requested that he spend 135 months (more than 11 years) in prison. (All the co-defendants were also found guilty.) Rothman posted the $500,000 bond and remained under house arrest until the sentencing hearing in June.

Ten days before the hearing, Hirschhorn filed a new motion: he wanted the court to grant an evaluation to determine Rothman's competency to proceed to sentencing. *Dusky* applies at this stage, too, because defendants must fully grasp the situation before them. Simultaneously, a judge who was not part of the Medcore case appointed Raquel Rothman as her father's emergency temporary guardian on the grounds that he was incapacitated.

When a person is ruled unable to meet the Dusky standards, the law permits a competency restoration—a forced stay at a prison hospital or outpatient clinic during which the defendant can be appropriately medicated for their condition and educated on the criminal justice system. They may be trained to answer questions such as, "What is the role of a jury?" and "What is a plea?" Eventually they are deemed fit to return to court, and the case resumes.

But what if they are never deemed fit? Dementia is irreversible; no one makes a recovery. The medications available for Alzheimer's may slow disease progression, but they don't stop or reverse it. The June 2021 approval of aducanumab for mild Alzheimer's was controversial because neither of the clinical trials that led to the approval showed any improvement in symptoms. Lecanemab, approved in January 2023, also does not reverse symptoms. "Dementia just gets worse and worse," Wood says.

That means that a defendant with Alzheimer's will undergo a restoration process that is doomed to fail. They typically end up committed to the hospital for longer periods than people who have more treatable psychiatric conditions, explains Yale University psychiatrist Tobias Wasser, a former chief medical officer at a forensic psychiatric hospital.

In response to Hirschhorn's presentencing evaluation request, the judge appointed Ranjan Duara, a neurologist who directs the Wien Center for Alzheimer's Disease and Memory Disorders at Mount Sinai Medical Center in Miami, to conduct the competency examination. Duara filed his report to the court in August 2009. Rothman did not have Alzheimer's, nor was he malingering, Duara wrote. He had frontotemporal dementia.

HUMANS HAVE AN INNATE ETHICAL COMPASS. THE MEDIAL frontal region and anterior temporal region of the brain help us evaluate moral questions. The classic trolley problem draws on this feature: A train is headed toward five people tied to the track; Do you change its course to kill just one person instead? "It's very hard to do something for the greater good, for the greater many, if you feel like you're hurting somebody directly," Mendez says.

Frontotemporal lobe dementia (FTD) attacks this moral circuitry. It erodes the parts of us that sympathize, that make us feel self-conscious, that help us distinguish right from wrong. A person with frontotemporal lobe dementia may know that stealing is wrong, but if you ask them whether it was wrong of them to take a scarf from a store without paying, they may say no. "They don't feel that their actions are wrong but that the action itself is wrong," Mendez says. FTD would not lead a reputable obstetrician to design an elaborate scam to defraud Medicare, but it could stop him from recognizing his participation in the ruse.

In the U.C.S.F. study that identified high rates of criminal behavior among people with dementia, those rates were highest among the subset of patients with FTD: 64 of 171 patients, or 37 percent. "Patients with FTD can commit criminal violations while retaining the ability to know the moral rules and conventions," Mendez wrote in a 2011 paper describing the predilection of people with FTD to break the law.

Duara was struck by Rothman's lack of insight about what was going on at Medcore, as well as his lack of remorse. "He really didn't think he had done anything wrong," Duara says. "He didn't seem to ever admit that he had made any errors in judgment by being involved with this clinic." An MRI scan revealed that the anterior part of Rothman's temporal lobe, the brain region just behind the ears, had shrunk. "There was no question there was something degenerative going on in the brain," Duara says.

Given Duara's departure from the assessments of previous experts, the prosecution called for a longer evaluation. The judge sent Rothman for a 10-day evaluation at the Federal Medical Center in Rochester, Minn. The psychologists there concluded that Rothman was faking his symptoms, but the judge disagreed with their findings—it turned out that the evaluators had no experience with dementia. In August 2010, 17 months after Rothman was found guilty, the judge ruled that Rothman was incompetent to proceed to sentencing.

The prosecution wanted assurance that Rothman would never become fit for sentencing. Rothman surrendered to the Bureau of Prisons medical facility in Butner, N.C., for evaluation. This facility is well known among forensic psychiatrists (Unabomber Ted Kaczynski was

housed there until his death in June 2023). The report provided by the forensic psychologist handling Rothman's evaluation confirmed that Rothman had not gotten any better and never would. On June 10, 2011, he was released to the custody of his family.

By this time, Rothman's wife had filed for divorce. Raquel Rothman relocated her father to an assisted living facility in Miami, which he could leave only with a member of the staff or his family. She was ordered to call her father's probation officer every week to confirm that he was at the facility and complying with the restrictions on his whereabouts. "I had two alarms on my phone for 10 years to make sure I didn't miss a single phone call," Raquel says.

TO THE END, DEMENTIA IS A SHAPE-SHIFTER. DUARA REMAINED Rothman's doctor, filing dozens of reports to the U.S. Department of Justice over eight years. In 2016 he took another look at Rothman's brain with a PET scan and found the image more consistent with atypical Alzheimer's—a variant that mimics frontotemporal dementia and causes problems with judgment, insight and executive function.

In 2019 the Department of Justice filed a request that the case against Rothman be dismissed, and the court agreed. Duara, who checked on Rothman most recently in January 2023, says that his patient was "moderately to severely impaired." According to Raquel Rothman, her dad can no longer take care of himself and barely speaks. During a visit at the assisted living facility in the summer of 2022, when she was sitting in Rothman's room, watching him "go in and out of consciousness," she says he started moving his hands delicately through the air, thumb and forefinger pressed together. "He was suturing in his sleep," she says.

Rothman wasn't necessarily subject to any injustice. He may have avoided prison because the justice system was working well or because it was working poorly. Maybe he had a fair and careful judge—or a really good lawyer. Other defendants with dementia facing similar charges have not fared nearly as well. Wisniewski, who treats dementia at N.Y.U. Langone Health, recalled a patient—a physician—who began writing unnecessary narcotic prescriptions and ended up in prison for 15 years. "He was barely cognizant of his name after five years," Wisniewski says, "but he stayed incarcerated. Dementia patients are dealt with in an extremely cruel fashion."

Among the solutions suggested by experts like Arias would be an elderly, cognitively impaired equivalent of juvenile court, which recognizes that juveniles should be held to different legal standards than adults because their brains are not fully developed. At the federal level, that change would have to be led by the Department of Justice, which is currently more focused on protecting people with dementia *from* criminals such as scam artists rather than on helping people with dementia who *are* criminals. States are hamstrung by political will. Another option would be to allow a plea of "not guilty by reason of dementia" or to enact sentencing limits similar to those protecting juveniles from lifelong incarcerations.

When the Bureau of Justice Statistics collects data on correctional facilities, it doesn't ask about dementia specifically, so the precise number of inmates suffering from it isn't known. One 2012 study estimated, somewhat unhelpfully, that dementia rates among inmates range from 1 to 44 percent depending on the type and size of the prison. But given the prevalence of dementia in the older population in general, it's reasonable to assume that number, whatever it is, is trending upward: In 2013 people older than 55 made up 10 percent of the state prison population—a 7 percent increase from 20 years earlier. One report projected that by 2030, people age 55 and older will make up a third of the U.S. prison population.

If prisons are meant for rehabilitation, then why keep people locked up when they no longer understand why they are even there?

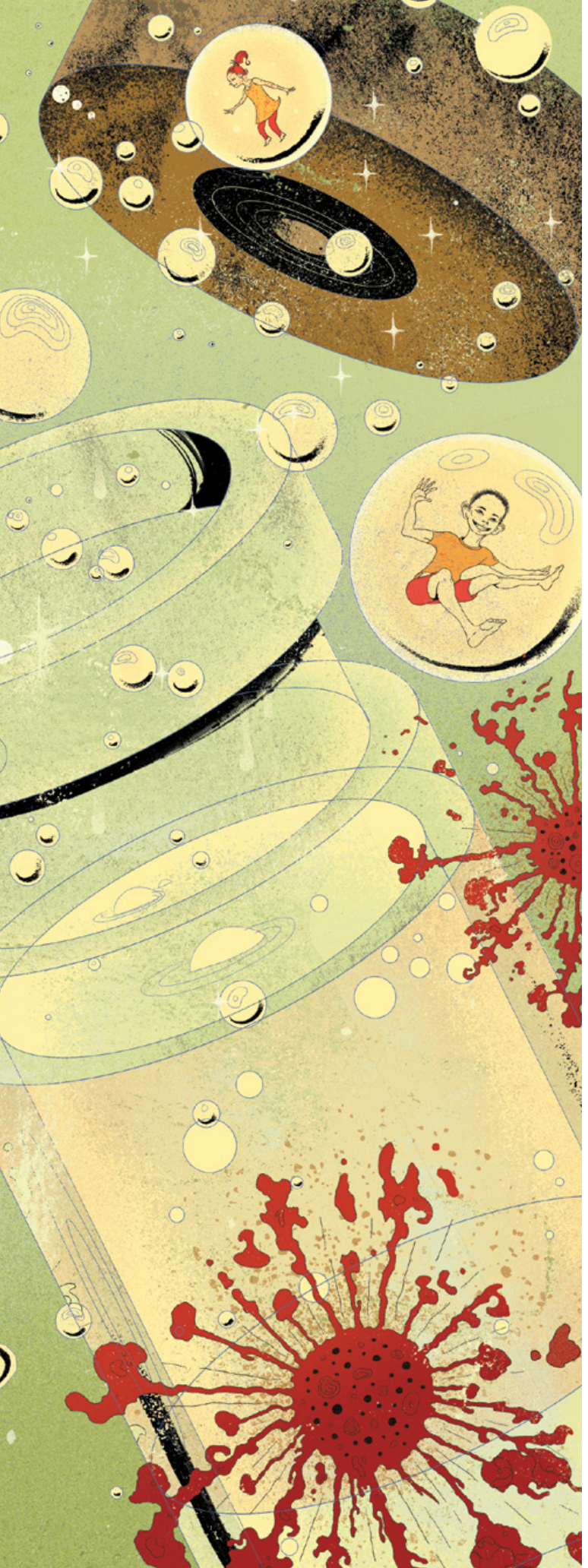
The reasons for this increase are multifold. When the U.S. banned the death penalty from 1972 to 1976, life sentences became more common and never receded even when the ban was lifted. The large Baby Boomer population has been entering the phase of life when dementia is most common, leading to increasing diagnoses. The lack of exercise and the psychological turmoil of prison life may exacerbate cognitive decline among aging inmates, especially if they have other mental health issues.

Most correctional systems offer no geriatric or dementia care services. Prison memory wards, such as the one that opened in 2019 at the Federal Medical Center Devens in Massachusetts, could help keep vulnerable inmates safe. But such interventions drive home a contradiction: If prisons are meant for rehabilitation, Arias explains, then why keep people locked up when they no longer understand why they are even there? Arias is continuing to accrue data from attorney interviews to evaluate the purpose of our criminal justice system. "Is there a willingness to concede that incarcerating someone with dementia," she asks, "is, maybe, questionable?" SA

FROM OUR ARCHIVES

Dementia in Prison Is Turning into an Epidemic. Sara Novak; ScientificAmerican.com, September 27, 2022.

scientificamerican.com/magazine/sa



MEDICINE

The Long Shot

After decades of frustration, scientists finally have successful vaccines and treatments for the respiratory disease RSV

By Tara Haelle

Illustration by Cristina Bencina

FOR MANY PEOPLE, AN INFECTION WITH RESPIratory syncytial virus, or RSV, is little more than a troublesome cold. But the virus poses a serious danger to young infants, older adults and immunocompromised people. The disease is the leading cause of hospitalization in infants in the U.S. and was particularly bad in the 2022–2023 season. An estimated 58,000 children and 177,000 older adults in the U.S. are hospitalized with RSV every year. As many as 300 of these children die, along with approximately 14,000 older adults.

After a decades-long search, vaccines for RSV are finally here. Scientists have been working on the shots since soon after the virus was discovered in 1956. But some disastrous clinical trials in the 1960s and dozens of other failed attempts stymied progress for many years. Now not just one but two

RSV vaccines for older adults have been approved by the U.S. Food and Drug Administration and the Centers for Disease Control and Prevention. As of this writing, a vaccine given to pregnant people, designed to protect infants after birth, was on track to be approved by the end of the summer. The breakthrough leading to these developments happened once researchers solved a 50-year-old mystery about the virus by examining the shape of its proteins. The discovery has ushered in a new era of vaccine development using designs based on the structure of proteins—the same approach that enabled the rapid development of a COVID vaccine.

Until recently, the main way to prevent RSV infection was the usual hygiene practices used to prevent common colds, such as wearing a face mask, washing one's hands and avoiding sick people. There was also one medication: palivizumab, a short-acting monoclonal antibody that provides passive immunity (protection with antibodies created outside a person's own body) to infants for up to one month at a time. But palivizumab, which was approved in 1998, requires multiple doses that cost more than $1,800 each. The drug is licensed for preterm infants born before 35 weeks who are younger than six months at the beginning of the RSV season, which starts in the fall. The American Academy of Pediatrics recommends restricting the antibody's use to the most vulnerable of these infants because of the cost.

A GRIM HISTORY

THIRTY YEARS BEFORE that drug debuted, scientists were already working on an RSV vaccine intended to save lives. To their horror, it took lives away. In 1966 four clinical trials tested a vaccine made with an inactivated form of the virus in children who had never gotten RSV before. In one of the studies, 80 percent of the vaccinated children were hospitalized when they later contracted the virus itself, and two toddlers—a 14-month-old and a 16-month-old—died. Typical hospitalization rates for children with RSV are in the single digits, says Ruth Karron, a pediatrician and director of the Johns Hopkins Vaccine Initiative. Otherwise healthy children do sometimes die from RSV, but that is most likely to occur in the first six months of life, so the deaths of toddlers were especially telling.

"As you can imagine, this sort of stopped vaccine development for a very long time," Karron says. "You took a pathogen that, even then, didn't kill that many children, and it killed children."

The disaster was traced to a phenomenon called antibody-dependent enhancement, in which the body produces antibodies that don't adequately protect it and instead exacerbate the infection. Antibody-dependent enhancement had occurred with an early version of a measles vaccine in the 1960s that was later pulled from use, and it has since been reported with the dengue fever vaccine.

But the mechanism that causes this problem varies depending on the pathogen. With dengue, for example, there are four types of the virus, and antibodies to one do not protect completely against all the others. So when a person develops antibodies in response to one dengue serotype and then becomes infected with another, the body tries to fight the second infection with the antibodies from the first and fails, while the infection worsens. The problem with RSV was that scientists didn't know what caused its antibody-dependent enhancement.

For the next two decades RSV vaccine progress stagnated. Researchers developed multiple live attenuated vaccines using virus that was weakened instead of neutralized, or deactivated. These didn't cause enhanced disease, but they also didn't make it far in clinical trials. "The problem with live attenuated vaccines is that you've got a relatively small therapeutic window, meaning if they're not attenuated enough, they will cause disease. Too attenuated, and they won't be immunogenic enough to cause immunity," says Barney Graham, a vaccinologist and senior adviser for global health equity at the Morehouse School of Medicine, who has spent his career studying RSV vaccine development for children but was not involved in those devastating early trials. "When you start putting it into lots of children, who have so much variability themselves, it's hard to get that therapeutic window to fit all of the children," says Graham, who was also instrumental in developing a COVID vaccine.

Before RSV vaccine research could lead anywhere fruitful, researchers needed to know what had gone so wrong in the 1960s trials to cause antibody-enhanced disease. The mystery wasn't solved until 2008, when Fernando P. Polack, founder of the Infant Foundation in Argentina, and his team at Johns Hopkins University published a study in *Nature Medicine* describing experiments with mice that demonstrated how the antibodies produced by the vaccinated children's immune systems bound to RSV but did not neutralize it.

With those antibodies failing to neutralize the virus, it proliferated, resulting in a lot of ineffective antibodies and a lot of viral antigens clumping together with those antibodies, Graham says. These clumps built up in the tissue, attracting immune system proteins that caused a cascade leading to inflammation. That inflammation damaged lung tissue and created mucus that constricted the airways and made the children sicker than they would have been with no preexisting antibodies. But a big question remained: Why didn't those antibodies adequately neutralize the virus? Later that same year a serendipitous meeting would answer that question and lead to the final steps necessary to make RSV vaccines a reality.

A TALE OF TWO PROTEIN SHAPES

IN 2008 JASON MCLELLAN, now a molecular biologist at the University of Texas at Austin, had just begun a postdoctoral fellowship at the National Institutes of Health Vaccine Research Center, where he met Graham. Graham, who was leading RSV vaccine efforts there, learned that McLellan, who specialized in mapping the atomic structure of proteins, wanted to work on something "a little off the radar," Graham says. "Well, we have no structural information on RSV yet," he told McLellan. Graham was particularly interested in the "F protein," the antigen that was the main target for RSV vaccine development.

The idea piqued McLellan's interest. "It became clear that RSV was one of the major childhood pathogens for which we didn't have a vaccine, so working on a vaccine that can help save the lives of babies and young children was very motivating," he says. The pair's goal—discovering the F protein's structure—would become the key to creating a successful vaccine. But the F protein isn't stable: when it fuses with a cell, allowing the virus to enter and hijack the cell to reproduce, it changes shape. Antibodies against the so-called postfusion shape—the ones produced by the immune systems of the children in the 1960s trials—don't fully neutralize the circulating form of the virus *before* it binds to cells, known as

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the prefusion form. But if a vaccine could induce antibodies against this form, they should bind properly with the virus's active form. The trick was to figure out what that prefusion protein looked like and how to lock it into that shape.

To do that, the two researchers first took a harder look at the other form, the postfusion protein. "That's the one that's easy to make; it's stable, and so it's relatively easy to work with," Graham says. Knowing the structure of both the prefusion and postfusion proteins would enable Graham and McLellan to understand how the protein morphs between the two shapes. By 2010 McLellan had determined the structure of the postfusion protein using x-ray crystallography. Next, to decipher the prefusion protein, his team needed to find an antibody that neutralized the virus without binding to the postfusion protein.

In collaboration with researchers at Xiamen University in China, McLellan and Graham screened over 13,000 mouse antibodies until they found one that effectively neutralized RSV's prefusion F protein without binding to the postfusion one. The winning antibody was about 50 times more potent at neutralizing the virus than palivizumab, the FDA-approved antibody against RSV. The finding suggested previous vaccine candidates had failed because none produced antibodies potent enough to neutralize the virus.

The researchers then used a similar human antibody to determine the F protein's structure. "After we had that structure, everything really fell in place," Graham says. "All of a sudden, we had a new, very vulnerable target on the virus for making a vaccine."

Now, finally able to see exactly where the antibodies attached to the protein, McLellan and the team substituted two amino acids in the sequence that encodes the F protein to create a covalent bond that effectively "stapled" the protein together, preventing it from pulling apart into its postfusion shape. They published their method in late 2013, then spent the next few years growing human cells that would produce the prefusion protein and learning how to purify it for use in a vaccine.

The first small clinical trials to evaluate the vaccine's safety began in 2017 and produced encouraging results two years later. By then, "RSV vaccines had a life of their own," Graham says, as the pharmaceutical industry took over their development.

McLellan, meanwhile, turned his focus to coronaviruses. The RSV work would ultimately pave the way for determining the spike protein structure of SARS-CoV-2, the virus that causes COVID, and enable Moderna, Pfizer and other companies to develop a COVID vaccine in record time. The era of protein-structure-based vaccine design—starting with figuring out a pathogen's protein structure and building a vaccine around it—had begun.

VACCINES ARRIVE

THE TWO PHARMACEUTICAL companies that took the lead in developing vaccines based on this science were GSK and Pfizer. The FDA approved GSK's Arexvy, the first RSV vaccine for adults 60 and older, on May 3 and then approved Pfizer's Abrysvo for the same age group on May 31. GSK said its vaccine is 94 percent effective against severe disease and 83 percent effective against symptomatic disease in adults 60 and older. Pfizer said its vaccine is 86 percent effective against severe disease with at least three symptoms and 67 percent effective against symptomatic disease with at least two symptoms in adults age 60 and older. A CDC advisory panel voted in favor of recommending that people in that age group may get an RSV vaccine in consultation with their health-care provider but stopped short of recommending them for all older adults. Both vaccines should be available this fall as the next RSV season begins.

The more challenging need was a vaccine to protect newborns, especially because immune systems less than four months old are too immature to respond to most vaccines and develop the immune memory needed to fight a disease. Researchers used the same approach that protects newborns from flu and pertussis—administering a vaccine during pregnancy so the parent's antibodies will cross the placenta to the fetus. An RSV vaccine would protect infants for the first six months after birth, when babies are most at risk for serious complications from the disease.

The FDA's Vaccines and Related Biological Products Advisory Committee voted on May 18 to recommend FDA approval for Pfizer's parental RSV vaccine candidate. Pfizer has said its RSV vaccine for pregnant people is 82 percent effective against severe RSV in newborns for up to three months and 69 percent effective through six months. The committee was impressed with the vaccine's effectiveness, but some members had reservations about its safety data.

The FDA advisory panel voted unanimously in favor of the Pfizer vaccine's effectiveness and 10 to 4 in favor of the vaccine's safety. The primary reason for the four nay votes for safety was that the premature birth rate was slightly higher in the vaccinated group but not statistically significantly so. "I think the four votes were really just an abundance of caution," Graham says. "They weren't saying it wasn't safe. They said they wanted more information before they said yes," although it's not easy to get that additional information until studies are conducted in the general population.

GSK stopped its own trial of a vaccine for pregnant people because infants born in the vaccine group were 38 percent more likely to be born premature.

Beyond vaccines, AstraZeneca and Sanofi announced in March 2022 that nirsevimab, a prophylactic monoclonal antibody drug similar to palivizumab, is 75 percent effective against cases of RSV that require medical care in infants younger than one year with no history of RSV—and the protection lasts five months, which is about the length of a typical RSV season. Europe approved nirsevimab in November 2022, and the FDA approved it in July 2023. A similar long-acting monoclonal antibody made by Merck, clesrovimab, is in late-stage trials.

One challenge will be assuring the protection of children in low-income families, who are already more vulnerable to worse outcomes from RSV. The U.S. Vaccines for Children program ensures all eligible children can access vaccines recommended by the CDC, even if they lack insurance. But that program doesn't currently include vaccines for pregnant adults, and as of this writing, it has yet to be determined whether the program will cover nirsevimab.

It's still not clear how insurance companies might decide whether and when to cover nirsevimab. Either way, by the end of 2023, it's very likely that infants, like older adults, will have at least one highly effective option to reduce their risk of RSV for the first time in the half a century since scientists began the effort. SA

FROM OUR ARCHIVES

RSV Is Spreading: What We Know about This Common and Surprisingly Dangerous Virus. Tara Haelle; ScientificAmerican.com, November 4, 2022.

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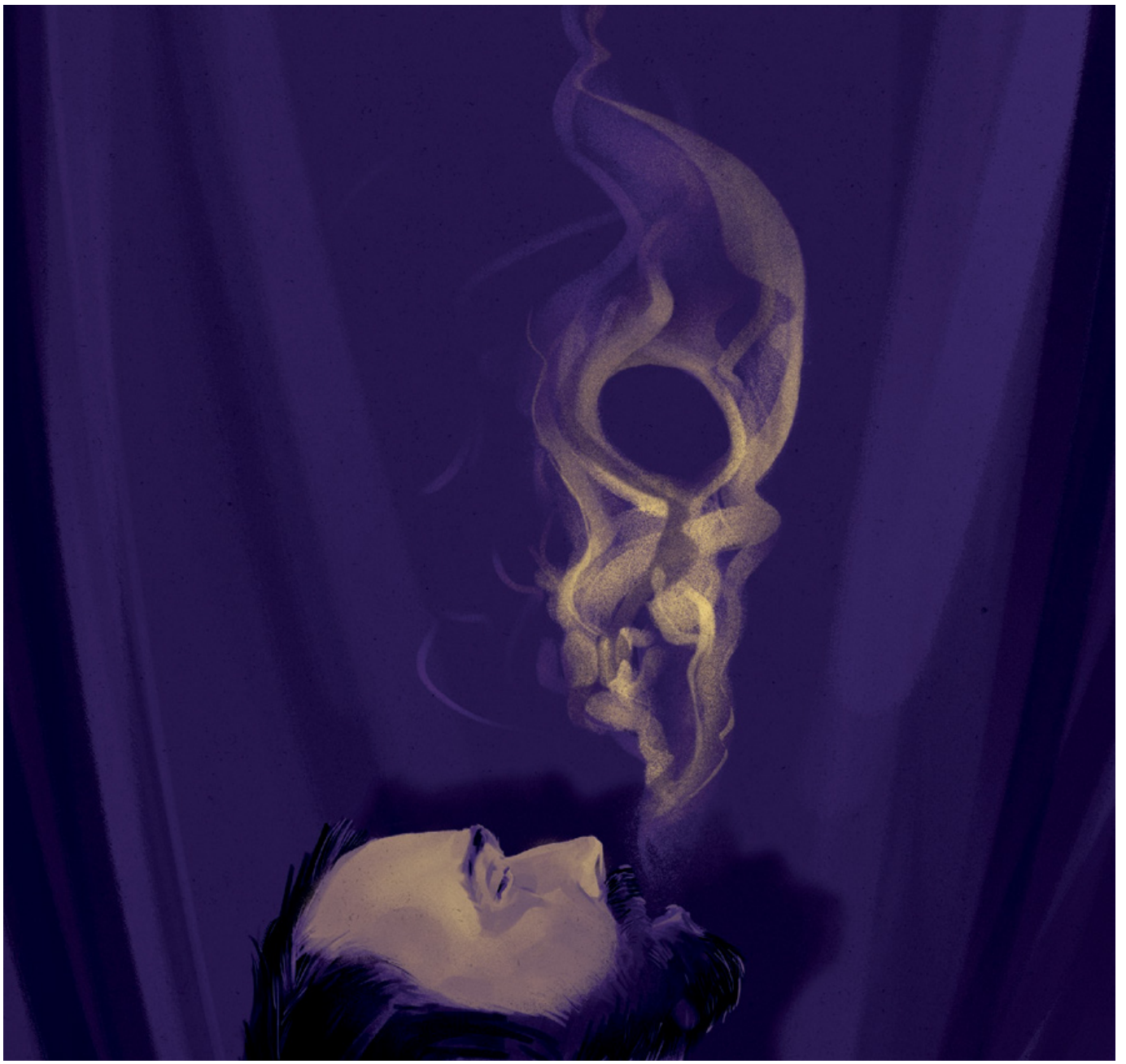
Smoking



Loosening tobacco's global grip

nature

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Smoking

For more on smoking visit nature.com/collections/smoking-outlook

Smoking kills. Maybe that's not the most original thought you've read today, but it's worth repeating. In 2019, around 14% of all deaths were caused by tobacco smoking — and were therefore entirely preventable. What a colossal waste.

The world is generally moving in the right direction. In countries deemed to have the highest level of economic and social development, there are now about as many former smokers as there are current smokers. That is encouraging, as is the decline in the global prevalence of tobacco smoking from 28% in 1990 to 20% in 2019. But we should not confuse progress with victory. As a result of population growth, there are actually more smokers now than there were in 1990 (see page S2).

Nicotine in cigarettes is highly addictive, which makes quitting smoking a miserable experience for many people. A new approach to help people kick the habit involves magnetically stimulating regions of the brain that are involved in addiction. The technique has already been approved for use in the United States, and it could improve considerably as researchers get a better handle on what goes on in a nicotine-addicted brain (S7).

Policies that encourage quitting and discourage new smokers will continue to be crucial to ridding the world of smoking. In general, high-income countries are ahead of their lower-income neighbours in this regard — the US Food and Drug Administration is even considering limiting nicotine levels in cigarettes, to make quitting easier. In low-income countries in Africa, however, even common anti-smoking measures such as raising taxes on cigarettes have proved difficult to implement, in part owing to the interference of tobacco companies (S4).

The negative health effects of smoked tobacco are unquestionable, but the role of nicotine itself in perpetrating these harms is not clear. The rising popularity of alternative nicotine delivery methods, such as e-cigarettes or vapes, is giving researchers more impetus — and more opportunity — to find out (S10).

We are pleased to acknowledge the financial support of Haleon in producing this Outlook. As always, *Nature* retains sole responsibility for all editorial content.

Richard Hodson
Senior supplements editor

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On the cover
Anti-smoking policies and new treatments will help to prevent tobacco use. Credit: Daniel Stolle

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AN AVOIDABLE HEALTH DISASTER

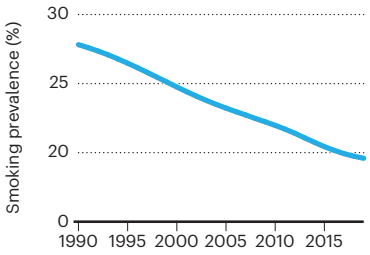
Tobacco smoking continues to place an extraordinarily heavy burden on global health. By **Richard Hodson**; *infographic by* **Mohamed Ashour**

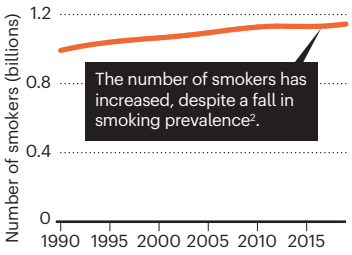
DEFYING PROGRESS

Efforts to discourage smoking have steadily reduced its prevalence from 27.8% of the global population in 1990 to 19.6% in 2019 (ref. 1). However, the total number of people who smoke has actually increased over the same period, owing to population growth.

1.14 BILLION PEOPLE

Global number of smokers in 2019





PREVENTABLE DEATHS

More than one in ten deaths can be attributed to smoking[2]. Most smoking-related deaths stem from one of just four non-communicable diseases (NCDs): ischaemic heart disease, chronic obstructive pulmonary disease, stroke and cancer of the trachea, bronchi and lungs.

- Non-communicable diseases **74.4%**
- Communicable, maternal, neonatal and nutritional diseases **18%**
- Injuries **7.6%**

ALL DEATHS

SMOKING-RELATED DEATHS

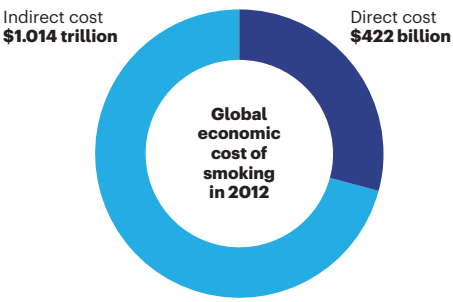
Smoking causes one in six NCD deaths

13.6% of all deaths are smoking-related.

200 MILLION YEARS of healthy life were lost to disability and death in 2019 as a result of smoking[2].

ECONOMIC STRAIN

Direct health expenditure on smoking-related diseases, as well as indirect costs of smoking such as lost labour due to disability and death, cost the world more than US$1.4 trillion in 2012 (ref. 3). These costs outweigh the value generated by the sale of cigarettes.

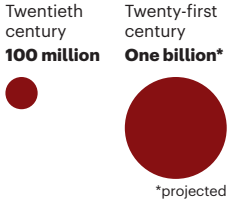


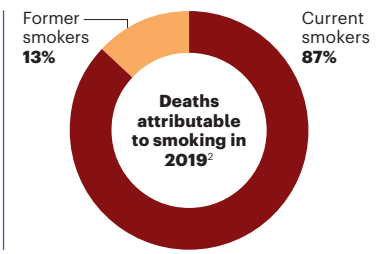
Annual value of cigarette sales in the United States[4]: **$94 BILLION**

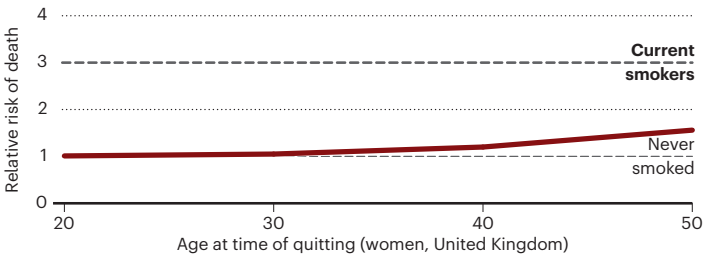
Annual economic loss in the United States due to smoking[4]: **$437 BILLION**

NEVER TOO LATE

If current smoking patterns do not change, by the end of the twenty-first century ten times as many people will have died from smoking as during the whole of the twentieth century[5]. The vast majority of people who will die will be those who continue to smoke; quitting at any age reduces the risk of a smoking-related death considerably[6].

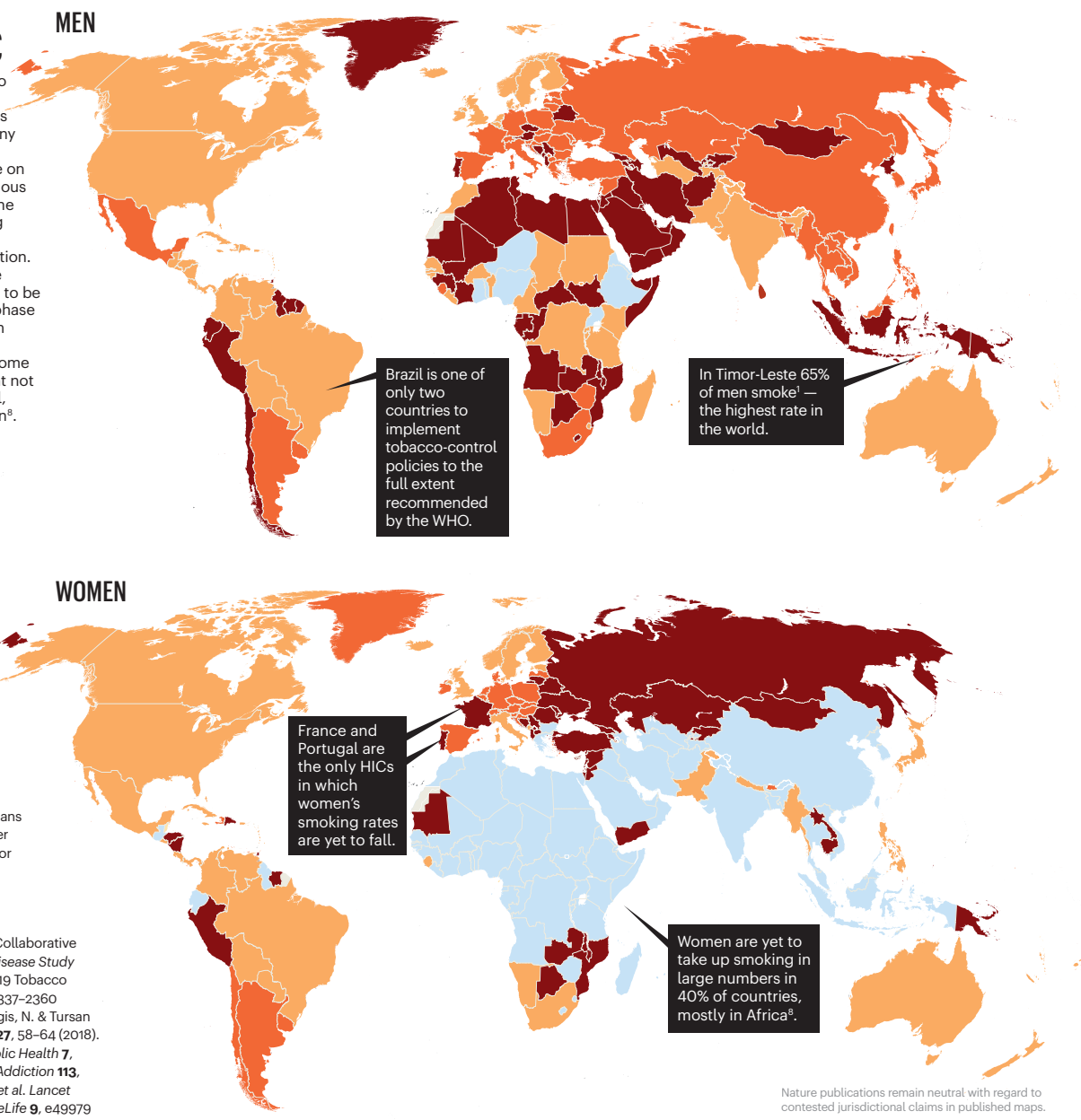






BATTLING AN EPIDEMIC

The fight against tobacco smoking has reached different stages in various parts of the world. In many high-income countries (HICs), smoking rates are on the way down from previous highs, thanks in part to the adoption of anti-smoking policies such as plain packaging and high taxation. Low- and middle-income countries are more likely to be experiencing an earlier phase of the epidemic, in which smoking rates are yet to decline. In some low-income countries, smoking might not yet have taken hold at all, especially among women[8].



'Not declining' in phase 1 means that smoking rates have never declined by more than 10% for men and 5% for women.

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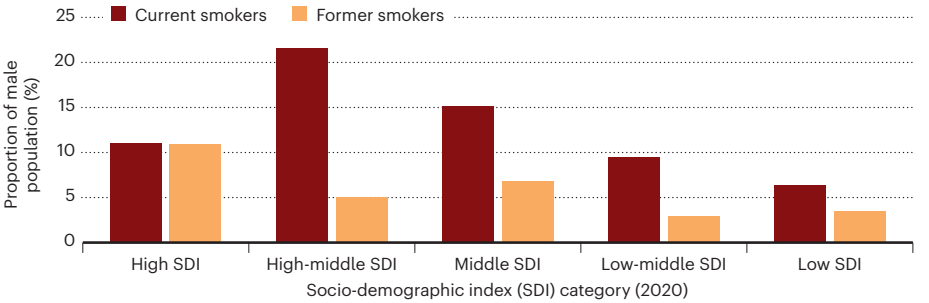
90%

Quitting smoking before the age of 40 avoids more than 90% of the excess risk of death[7].

A TURNING TIDE?

Policies that promote smoking cessation are common in countries with high economic and social development, and have led to roughly equal numbers of current and former smokers. In nations with lower development, where an increase in smoking might have occurred more recently, cessation efforts are yet to have as significant an effect[8].



Tobacco products are often displayed alongside sweets in some African countries.

TOBACCO FREE ASSOCIATION OF ZAMBIA

The battle against tobacco in Africa

Interference from the tobacco industry and a lack of resources make it difficult to strengthen anti-smoking regulations. **By Tammy Worth**

Fastone Goma, a physician and chair of the Zambia Non-Communicable Disease Alliance, has been working for more than 15 years to pass tobacco cessation legislation in Zambia. Bills have gone to several ministers of health, agriculture and commerce, trade and industry for their consideration. But they have never made it to the National Assembly for a vote.

Given the forces that hold sway over the country's economic policies, that outcome is not terribly surprising. "Zambia is one of the major tobacco producers in the sub-Saharan Africa region, so when we talk about tobacco control, it has to be balanced with the commercial interests of farmers and growers," says Goma. "It ends up in an endless cycle, all aimed at them not losing money from the sale of tobacco."

Goma is one of a group of individuals and organizations that have been working to combat the messages of the tobacco industry, educating lawmakers on how cigarettes and related products harm the nation's health and economy. He hopes that the Tobacco and Nicotine Products Control Bill, a draft of which was finalized in 2018, will succeed where others have failed. The country's current minister of health, Sylvia Masebo, has been supportive and has an encouraging record.

It is easy to see why anti-smoking legislation might not always have been a priority for African countries. Currently, the continent has the lowest rates of smoking in the world: in 2020, only about 10.3% of the population smoked according to the World Health Organization (WHO)[1]. Worldwide, smoking prevalence stands at 22.3%. But in the past decade, researchers and activists have begun raising red flags. Africa's improving economy and young, fast-growing population could drive a surge in smoking. The confluence of trends has not gone unnoticed by the tobacco industry, which focuses intense attention on the region and on governments that have been slow to introduce anti-smoking regulations. All of this, says Goma, could add up to an epidemic in the coming years.

Growth opportunity

Nowhere else has the number of smokers increased more since 1990 than in Africa — 104% in North Africa and the Middle East and almost 75% in sub-Saharan Africa[2]. There were about 66 million smokers on the continent in 2015; by 2025, it's estimated there could be 84 million[3]. It is one of only two parts of the world, along with the eastern Mediterranean region, where tobacco smoking is set to grow in the coming decade.

"Africa is in its nascent stages of development," says Peter Magati, an independent economist and tobacco researcher based in Kenya. He sees the region as "playing catch-up" to Europe and North America, and likely to encounter problems similar to those that development brought in those areas. "They have already been through this and we are following the same cycle, being perceived as a new market for tobacco companies," he says.

Africa's young people are a particular target. A 2022 analysis led by researchers at the University of Sierra Leone found that an average of 19% of adolescents aged from 11 to 17 in 22 African countries reported using tobacco products[4]. Zimbabwe ranked the highest at 47%. Rates of young men using tobacco were higher than those of women, at 24% and 14% respectively. This is similar to the split seen in Africa's adult population more generally.

"We are still on an upward trajectory in most of the countries in Africa," Goma says. He pins the most responsibility on tobacco companies, which he contends "are really targeting teens". As a result, he predicts, "in a few years' time we are going to see those increased rates among African adults".

Actions not taken

The researchers at the University of Sierra Leone found that breathing second-hand smoke was strongly associated with adolescent tobacco use. But there were several other factors that increased risk, including exposure to tobacco industry promotions and a lack of education about tobacco's health effects.

Some of these factors could be addressed by implementing recommendations from the WHO Framework Convention on Tobacco Control (FCTC). The FCTC was adopted by

the World Health Assembly in 2003 to stymie tobacco use globally through regulatory strategies. The main components include monitoring tobacco use, banning tobacco use in public spaces, providing cessation services to people who want to quit, placing graphic warning labels on tobacco products, banning tobacco companies from advertising and sponsorships and raising taxes on tobacco products.

So far, 43 of the 46 countries in sub-Saharan Africa have signed the FCTC. "Countries in Africa wanted to step forward," says Anna Gilmore, a public-health researcher at the University of Bath, UK. "They can't afford to pay for the health-care costs and damage [of smoking]," adds Gilmore, who is a member of Stopping Tobacco Organizations and Products (STOP), a global tobacco industry watchdog. "They were incredibly positive and helped drive through a strong treaty."

But despite their engagement in creating the FCTC, African countries have typically lagged behind when it comes to enacting its policies. Pictorial warnings on cigarette packages, smoking bans in restaurants and bars, and bans on displaying products in retail — policies that many high-income countries have followed for decades — have been adopted by only around one-third of countries in sub-Saharan Africa[3].

Industry pressure

The main reason that African countries haven't implemented more FCTC recommendations, according to researchers and activists, is the influence of the tobacco industry.

"I think of it in terms of power imbalances," Gilmore says. In countries with small gross domestic products (GDPs), she says, wealthy industries can interfere and influence in ways that they might not be able to in richer nations. "These companies are more outrageous in what they will do in low- and middle-income countries," she says.

A 2021 report[5] by the African Tobacco Control Alliance ranked 14 countries in sub-Saharan Africa according to how much influence the industry wielded over them, how transparent governments made their dealings with tobacco companies and what measures were in place to rebuff their advances. Zambia was found to have the highest level of interference, followed by Tanzania, South Africa and Mozambique.

In 2018, comprehensive tobacco legislation was announced in South Africa that included FCTC provisions such as requiring plain packaging on cigarettes, banning the display of tobacco products in retail and regulating e-cigarettes. The bill has yet to pass and, according to research by Gilmore and colleagues, industry efforts could be partially to blame.

For example, cigarette producer Japan Tobacco International responded by launching a campaign called #HandsOffMyChoices arguing against numerous aspects of the proposed bill, and conducted a survey that suggested there was little support for plain packaging among people in South Africa. And the Tobacco Institute of Southern Africa, an industry association, began a '#TakeBackTheTax' campaign that reflects industry arguments regarding the value of tobacco taxation and employment.

TOBACCO FREE ASSOCIATION OF ZAMBIA

Brenda Chitindi is the executive director of the Tobacco Free Association of Zambia.

"When people decrease spending on tobacco, they start spending more on health care and education."

There are also accusations that the tobacco industry attempts to influence policies by making payments to individuals. In 2021, Gilmore's research group published an analysis of documents provided by two whistle-blowers at the cigarette company British American Tobacco (BAT), one of the main players in Africa. The report claims that, between 2008 and 2013, BAT made payments totalling US$601,502 to individuals in the form of cash, wire transfers, campaign donations and expensive gifts[6]. The recipients included politicians and civil servants in Burundi, Comoros, Rwanda and Uganda, at a time when tobacco control legislation was being considered in all four countries. Uganda finally passed comprehensive tobacco legislation in 2015; regulation in the other three countries still falls short of FCTC guidelines.

Influence can also be subtler. Tobacco companies provide funding for public-policy think tanks, such as the IMANI Center for Policy & Education in Ghana, which has publicly opposed tobacco control and even the link between smoking and lung cancer. Furthermore, and against FCTC recommendations, tobacco companies in Africa often participate in corporate social responsibility programmes, such as providing scholarships to low-income students, or donating to COVID-19 relief funds. "In the United States and United Kingdom, the industry has been denormalized," Gilmore says. "But in Africa, the tobacco industry is still seen as acceptable and puts loads of money into maintaining that image."

Nature reached out to tobacco companies including Philip Morris International, Roland Imperial Tobacco Company and BAT for comment. Only BAT responded to questions regarding the industry's influence on FCTC uptake in Africa through e-mail: "We support many of the objectives of the World Health Organization's Framework Convention on Tobacco Control. This includes measures to reduce underage smoking, reinforcing the already well-established public awareness of the health risks of smoking, encouraging smoking cessation, and eliminating illicit trade in tobacco products. We believe regulation should be based on sound evidence and wide consultation, respect legal rights, and be aimed at delivering harm reduction."

A taxing problem

One of the most effective tools to reduce tobacco use is raising the price of these products by imposing higher taxes on them. According to the WHO, increasing prices by 10% can reduce smoking rates by 5% in low- and middle-income countries[7]. The FCTC recommended tax rate is 75%; globally, the median tax rate is 60%. But in Africa, the median tax rate is just 34% — the lowest in the world[8].

Tobacco companies consistently fight tax increases. In South Africa, for example, industry-backed groups lobbied successfully in 2020 to keep taxes on cigarettes unchanged, at 40%. The typical arguments of these groups are that increasing taxes on tobacco products will reduce legitimate sales and increase illicit trade, with the net effect of decreasing governments' revenue — and thus putting numerous tobacco-related farming and manufacturing jobs at risk.

"Their pet arguments are about revenue," says Jeff Drope, a health-policy researcher at University of Illinois Chicago's School of Public Health. He thinks that concerns that revenue will fall if taxes go up are misplaced. "Consumption goes down, but revenue goes up because people are paying more taxes," he says. In the mid-1990s the South African government decided to increase cigarette taxes to 50% of

the retail price. By 2004, this tax had increased by 256% per pack, and smoking prevalence dropped from 32% to 24%. At the same time, government revenue increased 140% (ref. 9).

The risk of lost jobs might also be overstated by the industry. "Tobacco doesn't employ a lot of people," Drope says. In Zambia, more than two-thirds of the population relies on agriculture for their income, but only a fraction are growing tobacco. According to a 2017 report co-authored by Goma and Drope, cotton, tea, coffee and maize (corn) are the largest export-oriented agricultural commodities in Zambia, accounting for US$589 million in 2012, or 2.31% of the nation's GDP[10]. Tobacco, by contrast, accounted for just 0.4% of Zambia's GDP. Tobacco was being grown on 59,000 hectares by around 10,000 farmers; the other 4 crops were grown on about 1.5 million hectares by more than 1.2 million farmers. Cigarette-manufacturing facilities opened in Zambia in 2018 and 2019, by BAT and Roland Imperial Tobacco Company respectively, reportedly created fewer than 200 jobs for local workers.

Brenda Chitindi, executive director of the Tobacco Free Association of Zambia, says that the industry exaggerates the number of people employed in it by including family members of employees as workers in 'tobacco-farming households'. Some African farmers are also known to use children to reduce their labour costs, she says.

Drope also thinks that any job losses that do occur will be balanced by the creation of jobs in other sectors. "When people decrease spending on tobacco, they start spending more on health care and education, which are labour-intensive sectors," he says. "Often, there is a net gain in employment."

Tobacconomics, a tobacco-control think tank at the University of Illinois Chicago that counts Drope among its researchers, studied the potential results of tax increases in several low- and middle-income countries, including North Macedonia, Pakistan, Mexico, Argentina and Indonesia. The group found that these countries would end up with at least a small net employment gain if tobacco sales dropped because people would spend more on food, education and health, leading to job growth in these sectors (see go.nature.com/3yv2cuv).

Enforcement challenges

Despite industry pressure, some countries have passed legislation on the basis of FCTC recommendations. In 2007, for example, Kenya passed the comprehensive Tobacco Control Act — an action that Magati attributes to a constitution that allows citizens to propose legislation. In many other African countries, it must come from government officials. "Power here doesn't rest with a few individuals," he says. "The tobacco industry isn't able to influence here as it can in other places."

TRYGVE BOLSTAD/ PANOS PICTURES

Some tobacco plantations use children to reduce labour costs.

In 2014, Senegal also introduced comprehensive legislation and began requiring graphic health warnings on cigarette packages in 2017. By 2018, the government had raised tobacco taxes to 65%.

However, legislating is only part of the battle. Despite its intentions, Senegal has struggled to implement its plans for smoke-free spaces and warning labels. It is not alone in this: in many African countries, even when laws are put in place, local authorities lack the will, personnel and money to enforce them. "Governments are struggling with budgets and looking at immediate concerns like poverty and hunger, so enforcement agents have limited resources to function even when they are committed," Magati says.

There aren't a lot of data on how much African countries spend on tobacco control, but one estimate puts it at about $0.006 per capita[3]. Staving off the rapid growth of smoking that many fear Africa could experience will therefore take more than just a willing, educated government — it will also require advocacy from civil society and external funding.

Sierra Leone passed the Tobacco and Nicotine Control Act of 2022 last August. The bill came to be in part because of investments by the WHO in developing the law and providing data to illustrate the impact it would have on the country's health. Drope, meanwhile, is advising 22 countries on tobacco taxation. He works with local universities and think tanks to provide education on smoking and thinks these kinds of collaboration are crucial to helping the continent kick the habit. "When we are all singing from the same song sheet, it really helps," he says. "It takes folks getting bombarded with the same message from a lot of different messengers."

In Zambia, laws that prohibit smoking in public places are routinely ignored, Goma says, as is a ban on sales to people aged 16 and younger. In fact, he frequently sees young children selling individual cigarettes. Advertising restrictions are also not adhered to. "They put displays targeting children near the sweets and other children's foods," Chitindi says.

"Because rates of tobacco use are still low, everyone thinks it's not a problem," Goma says. This is misguided, he says. "The future is what we must be worried about because we are on an upward trajectory. If we don't control smoking rates among the young now, we are bound to have a big problem on our hands."

Tammy Worth is a freelance health-care reporter based in Kansas City, Missouri.

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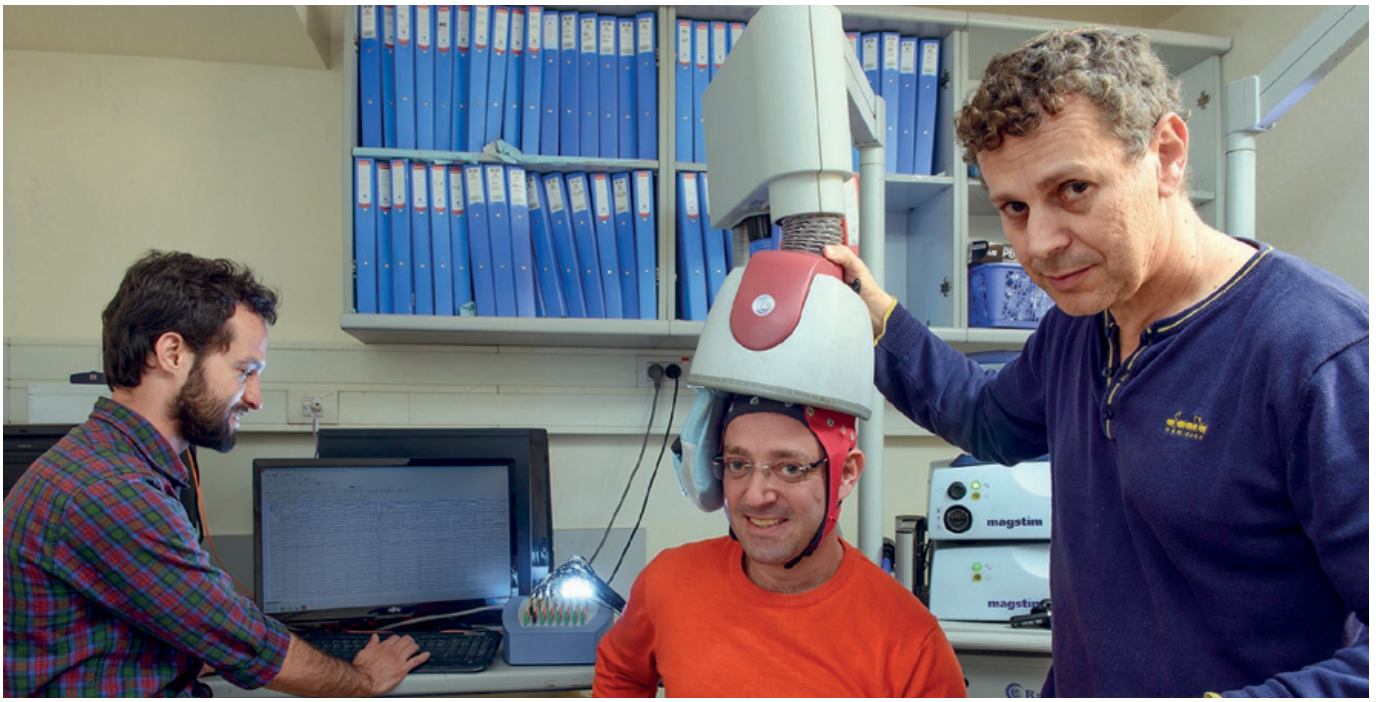


DANI MACHLIS/BEN-GURION UNIV. OF THE NEGEV

Neuroscientist Abraham Zangen (right) and two of his students with an early version of their repetitive transcranial magnetic stimulation system.

A stimulating solution to smoking

Magnetic pulses delivered to the brain could help people to overcome addiction to cigarettes, but there is still a lot to learn. **By Simon Makin**

Galit Blecher never wanted to start smoking, but during her service in the Israeli military, she succumbed. "Everyone in Israel smoked in the army," she says. Having held out for more than one year, an especially tedious posting broke her resolve. "I was driving three hours through the desert, several times a week," she says. "I was falling asleep."

After returning to civilian life, she gave up smoking twice with the help of an antidepressant drug called bupropion (also known as Zyban), which reduces cravings and withdrawal, but she started smoking again each time. Then, six years ago, she joined a clinical trial of a new treatment targeted at people who had tried and failed to quit smoking. She hasn't smoked since. "After Zyban, there was always a craving when I saw other smokers," Blecher says. "This time it's a real aversion; I can't stand smelling cigarettes."

The treatment that helped Blecher is called repetitive transcranial magnetic stimulation (TMS), and uses magnetic fields to stimulate regions of the brain involved in addiction. The effect on quit rates in the trial was modest, but comparable to bupropion, which blocks nicotine receptors in the brain. It was enough to convince the US Food and Drug Administration (FDA) to approve, in August 2020, the use of repetitive TMS to help people quit smoking.

However, the scientists working on this new approach to giving up smoking are not finished yet. With so many variables in how repetitive TMS is delivered, researchers from around the world are now aiming to pool their knowledge and standardize methods to help the field move forwards. Understanding of the neural circuitry that underlies addiction is improving, which is helping to find ways to make the treatment more effective. And some researchers are exploring the use of brain imaging to tailor treatment to individuals.

A pivotal trial

Blecher was one of 262 smokers who were recruited to test the treatment. "These were very heavy smokers, for many years," says Abraham Zangen, a neuroscientist at Ben-Gurion University of the Negev in Israel, who led the study[1]. Half of the participants experienced real stimulation of their brains through a coil inside a helmet, whereas the other half received a sham stimulation from a second coil that produced similar sounds and sensations on the scalp but did not produce a magnetic field that affected the brain.

The stimulation was aimed at their lateral prefrontal cortex and the deeper-lying insula, with the intensity set to 120% of the level needed to make each recipient's thumb move. "To make brain stimulation effective, you need to use meaningful intensities and frequencies," Zangen says. This is uncomfortable for patients. "It's like an electric shock to the head, you feel your jaw clamping," says Blecher. "It wasn't that painful, but it wasn't pleasant."

Blecher and her fellow participants initially received the treatment every weekday for three weeks, and then once per week for another three weeks. For people in both the treatment and sham groups, each half-hour

session began with provocation cues designed to elicit cravings, to activate the neural circuitry. "When a circuit is active, it's more liable to change," says Zangen. Afterwards, all participants received a short motivational talk.

Following the treatment period, participants' smoking behaviour was monitored for four weeks, both by self-reporting and by monitoring urine for cotinine – a product formed when nicotine is broken down in the body. Anyone still not smoking at this point was assessed again 12 weeks later. By this time, 28% of people who received the full treatment protocol were still not smoking, compared with 12% of those who received the sham stimulation. People in the treatment group also reported greater reductions in their cravings for cigarettes.

"Looking at the percentage of quitters, it's not that great," says Zangen. Other treatments, such as nicotine replacement therapy, were approved by the FDA on the basis of higher quitting rates, he says. But these treatments were usually tested on less heavy smokers who had not tried and failed to quit in the past as many times as Zangen's participants had. Some of those studies also based their results purely on self-reported behaviour and breath testing for carbon monoxide, which can detect whether a person has smoked only within hours of a cigarette. "You can find traces of cotinine after a single cigarette smoked a week ago," says Zangen. "The numbers are small because our criteria for quitting are very strict, but they're absolutely clinically meaningful."

The side effects of magnetic stimulation also appear to be minor. During the trial, the most common adverse effects were headaches and discomfort. Nevertheless, the now-approved treatment can be carried out only under medical supervision because of the risk of seizures. Although none of the participants experienced seizures during his pivotal trial, Zangen says that reports from treating other conditions suggest that around 1 in 5,000 recipients of TMS might experience a seizure[2].

"If we reduce excitability of the insular cortex, we're going to reduce cravings."

Some health insurance providers in the United States already cover TMS as a treatment for depression, but not yet for smoking, says Zangen. "But they should, because the cost of hospitalization, and lost working days due to chronic obstructive pulmonary disease, and cancers and so on, are much higher," he says. The treatment is currently available in more than 50 centres and psychiatrists' offices, mainly in the United States, with a few in Europe and India. Psychiatrists and physicians can refer someone to a TMS centre, and the centres also market the treatment directly to consumers.

Craving success

TMS was first approved for treating depression in 2008. Approval for treating obsessive-compulsive disorder followed ten years later. Its use in addiction is just beginning: the trial that Blecher participated in was the first multicentre randomized controlled trial of non-invasive brain stimulation as treatment for any form of addiction. "Targeting brain circuits responsible for symptoms has proven valuable for treating a variety of brain disorders," says Michael Fox, a neurologist at Harvard Medical School in Boston, Massachusetts. "We're optimistic it can help patients with addiction."

Addiction is not one behaviour, but a cycling pattern of recurrent relapse. Characteristics of this cycle include increasing sensitivity to drug-associated cues and the anticipation of drug rewards, coupled with decreasing sensitivity to those rewards when they come. People also experience impaired self-control, enhanced stress and negative emotions. Neuroscientists have pinpointed many brain regions involved in these states and behaviours, including the prefrontal cortex, which implements self-control, and the insula, which is thought to integrate autonomic information with motivation and emotion, and so give rise to the experience of cravings.

Early in Zangen's career, he worked on reward processing in animal models at the National Institute on Drug Abuse in Baltimore, Maryland. He learnt that electrically stimulating a rat's brain affected certain receptors involved in reward circuitry in the opposite way to repeated exposure to cocaine. "I thought, we must study whether stimulation in specific areas can induce behavioural changes in addiction," he says. In 2007, then at the Weizmann Institute of Science in Rehovot, Israel, Zangen published a paper demonstrating precisely that[3]. "This was the first ever study showing that brain stimulation, in rats, can reduce drug-seeking behaviour," he says. "At the same time, I started to develop applications of these animal studies to humans."

The first studies of repetitive TMS for smoking cessation, which stimulated the prefrontal cortex, found encouraging but impermanent effects. In search of a longer-lasting impact, Zangen and his colleagues began to look deeper into the brain, towards the insula. Another 2007 study[4] found that people who experienced damage to the insula were more likely to lose their smoking addiction than were people with damage elsewhere in the brain. Zangen's hypothesis was that electrically stimulating the insula could have similar results, by interfering with cravings. "If we reduce excitability of the insular cortex, we're going to reduce cravings," he says.

The standard 'figure-of-eight' coils that were used in the first human trials did not penetrate far enough into the brain to hit the insula. So Zangen used a new design that he had helped to develop during his time in the United States that could reach deeper regions of the brain[5]. The patent for this coil is now held by BrainsWay, a medical technology company in Burlington, Massachusetts, which developed the coil used in the trial and now supplies the equipment to treatment centres (Zangen is a scientific consultant for BrainsWay). Other researchers are now studying how the coils that Zangen and his colleagues developed could be used to target several other brain regions.

Unexpected explanations

Research into TMS has found that high-frequency stimulation typically makes an area of the brain more excitable, whereas low frequencies can reduce activity. Because Zangen and his team were aiming to suppress cravings, they expected that low frequencies directed at the insula would have the desired effect. To their surprise, the opposite was true: high-frequency stimulation proved to be effective[6].

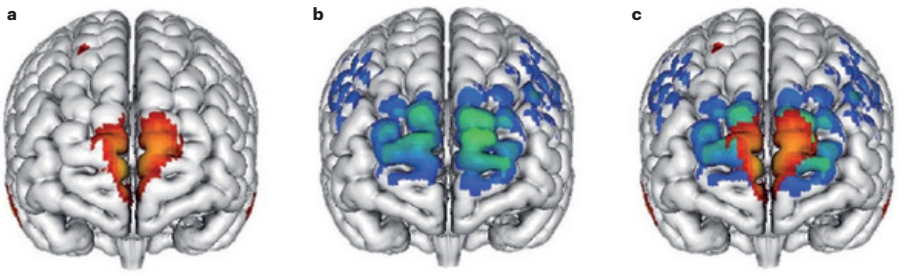
One possible explanation for this counterintuitive result is that, although the acute effect of high-frequency TMS is to increase excitability, the long-term effect of repeated stimulation could instead be suppressive. "If we stimulate the pathological circuitry daily, for several days, we [might] disrupt the processing of information," Zangen says. "That's one way to explain it."

It's not the only theory, however. "The other is that we don't reach all the way to the insula," says Zangen. Support for the idea that the treatment's effect might come from stimulating a different brain region can be found in a study of people with brain damage that was published last year[7]. A team led by neurologist Juho Joutsa at the University of Turku in Finland, mapped the brains of 129 people, all of which had areas of damage. All the participants were smokers at the time they acquired these lesions, but 34 of them had quit immediately after injury and not craved cigarettes since.

The brain lesions in those who had stopped smoking were not all in the insula. "There were many lesions that led to disruption of smoking addiction that didn't hit the insula, indicating it's not the whole story," says Joutsa. All the lesions that led to smoking cessation did, however, share a common brain circuit. Joutsa calls this the addiction remission network, in

ZAPPING AND MAPPING

A study of people with brain damage[7], some of whom quit smoking following their injury, associated activity in the medial frontopolar cortex with remission from addiction (**a**). Analysis of the brain regions that are excited by transcranial magnetic stimulation used to aid smoking cessation (**b**), which is intended to target the insula, shows that it is ideally positioned to stimulate the frontopolar cortex (**c**). This could explain the treatment's effects on addiction.



SOURCE: REF. 7

which many parts of the brain form different nodes. Some of these areas are positive nodes — that is, activity in these areas is associated with increased activity elsewhere in the network. Other brain regions form negative nodes that are associated with reduced activity elsewhere, probably owing to inhibitory connections to the network.

> **"We need a village of expert people working together to solve this."**

This discovery might have huge consequences for understanding how repetitive TMS helps people to quit smoking. It suggests that to benefit people with addiction, a device that stimulates brain activity should target negative nodes. And after scrutinizing Zangen's work, Joutsa thinks that might be exactly what their TMS therapy is doing. "They were kind enough to share the model of the fields generated by their coil, and the strongest activation was actually in the medial frontopolar cortex," says Joutsa — the largest negative node in their network. "That aligns perfectly with their excitatory stimulation to that region," he says (see 'Zapping and mapping').

Evidence is now pointing to the frontopolar region as being a key treatment target, says Hamed Ekhtiari, a psychiatrist at the University of Minnesota in Minneapolis. "When we expose people to drug-related cues, the frontopolar area is activated," he says. The medial frontopolar cortex connects not just to the insula that Zangen was intending to target, but also to several parts of the limbic system, such as the amygdala and nucleus accumbens. "These are important for arousal, for being excited about drugs," Ekhtiari says. Stimulating this one area of the brain could therefore affect numerous other regions that are involved in addiction. "My idea is that when we target the frontopolar area, we are modulating those subcortical areas in a beneficial way," Ekhtiari says.

Finishing touches

As researchers learn about where and how to optimally stimulate the brain, repetitive TMS treatments could become increasingly sophisticated. Devices that could target multiple regions in different ways are already being developed. "That's where the field is slowly moving," says Joutsa. Some regions could be excited while others are suppressed, for instance. According to Zangen, BrainsWay is working on a multichannel stimulator. "I have a prototype in my laboratory," he says.

The region being targeted is not the only variable associated with TMS: the frequency, intensity, duration and pattern of stimulation could also affect outcomes, as could the number of treatment sessions. Much of this has barely been explored, let alone optimized. "The parameter space is huge," says Joutsa. "I hope our findings help narrow down the spatial part, so we at least know where to target."

The uncertainty in how best to administer TMS for addiction has led to a wide variety of trial designs, which is partly why a generally supportive meta-analysis of the field, published last year[8], carried the caveat that the available evidence enabled the authors to have only a low level of confidence in their evaluation. To address this problem, many researchers working in the field have begun to collaborate under the banner of the International Network of tES/TMS Trials for Addiction Medicine (INTAM). Their aim is to share protocols and propose best practices, identify gaps in their knowledge and accelerate the creation of effective treatments for addiction based on non-invasive brain stimulation. "We need a village of expert people working together to solve this," says Ekhtiari, the lead author on a consensus paper[9] the group published in 2019. "We try to harmonize efforts around the world, to make sure people are informed about what different labs are doing."

Ekhtiari is also pursuing another kind of optimization: personalization. "The brain is very different across different people," he says. This means that exactly where to optimally stimulate the medial frontopolar cortex, for instance, might vary between people. Ekhtiari and his colleagues are looking for ways to use brain imaging to characterize these differences and increase the precision of targeting. A team led by researchers at Stanford University in California are already personalizing repetitive TMS treatment in this way. One clinical trial, using a protocol called SAINT (Stanford accelerated intelligent neuromodulation therapy), found a 53% reduction in symptoms of depression in its active treatment group, compared with 11% in the group that received the sham stimulation[10] — a result that led to FDA approval last September. "That's the idea we have for nicotine, and other types of addiction," says Ekhtiari.

Many researchers hope repetitive TMS will be effective not only for smoking cessation but also for treating a wide range of substance and even behavioural addictions. Already, Joutsa and his colleagues have found that brain lesions that are associated with a lower risk of alcohol abuse show similar connectivity patterns to the smoking network[7]. "It doesn't prove it's exactly the same finding in alcoholism, but it suggests the findings could be relevant for other substances of abuse," says Joutsa.

It is too early to tell whether repetitive TMS will have the impact on addiction medicine that its proponents envisage. But even in its current, nascent form, the technology is already being used to help some people quit smoking. The numbers being helped might be modest so far, but for those people for whom it works, the benefits are significant. "I'm really relieved I stopped smoking, because of the kids, the smell and my husband, who doesn't like it, and of course the health issues," says Blecher. "I'm never going back."

Simon Makin is a freelance writer in Reading, UK.

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E-cigarettes contain the highly addictive substance nicotine.

LIUDMILA CHERNETSKA/GETTY

Nicotine on trial

As e-cigarettes grow in popularity, the lack of knowledge about nicotine's impact on health is becoming more worrying. **By Anthony King**

After a few vigorous puffs of a burning cigarette, a smoker's lungs will be filled with a toxic cloud of more than 5,000 different substances. Their combined effects on health are well known: cancer, heart disease, stroke, chronic obstructive pulmonary disease and many more conditions. However, the most famous ingredient of a cigarette – nicotine – has generally not been considered a culprit in these health effects.

Nicotine is an alkaloid compound made by plants to deter herbivores, and it has been used as an insecticide. It poisons insects by binding to acetylcholine receptors in their nervous systems and causing their nerves to fire uncontrollably. In people, nicotine activates similar receptors throughout the nervous system, including those in the brain that affect the release of the feel-good molecule dopamine. The positive feelings this produces are why nicotine is addictive, and one reason why smokers crave cigarettes.

Although the addictive qualities of nicotine are well known, the damaging health effects of smoking are usually attributed to more-obvious toxins such as polycyclic aromatic hydrocarbons (PAHs), cadmium and the sticky brown tar left inside the lungs. "It has been said since the 1950s that people smoke for the nicotine and die from the tar," says Aruni Bhatnagar, director of the American Heart Association's Tobacco Regulation and Addiction Center at the University of Louisville, Kentucky.

But some researchers think that nicotine's influence on health could extend beyond just its addictive nature. Receptors that respond to nicotine are found not just in the brain, but also in tissues such as muscle. "It changes lots of functions in our bodies," says Maciej Goniewicz, a nicotine pharmacologist at Roswell Park Comprehensive Cancer Center in Buffalo, New York. "It's not a harmless compound."

Evidence for direct deleterious effects of nicotine consumption is limited. "It is hard to sort out because most nicotine exposure data comes from cigarette smoking," says Neal Benowitz, a physician and nicotine researcher at the University of California, San Francisco. With so many toxic compounds in tobacco smoke, separating nicotine from the rest of the noxious milieu has been a struggle. "We've done a poor job of dissecting out the various components of cigarette smoke," says Gerry McElvaney, a pulmonary physician at the Royal College of Surgeons in Ireland, Dublin.

Interest in the effects of nicotine is blossoming, partly because of the proliferation of e-cigarettes, or vapes. Vaping could provide a nicotine hit without the cancerous baggage, but it has become fiercely controversial owing to concerns that people who have never smoked – especially adolescents – will become hooked. In this new context, delineating the effects of a purer stream of nicotine is important, and numerous associations are being made, including purported impacts on heart health, cancer and brain development.

Issues of the heart

When a smoker tugs on a cigarette, their heart pumps harder, their blood pressure increases and certain blood vessels dilate or constrict. These effects are partly due to nicotine, which triggers the release of various neurotransmitters and hormones such as epinephrine. This process happens whether nicotine is inhaled from a cigarette or an e-cigarette, or chewed in the case of smokeless tobacco. What these acute impacts mean for long-term cardiovascular health, however, is disputed.

Researchers at the American Heart Association think that the stress nicotine puts on the heart is concerning. "We believe that much of the cardiovascular effects of smoking are because of nicotine," says Bhatnagar. When nicotine is inhaled, it changes the electrical conductivity of the heart that keeps it beating in sync. Nicotine can knock this delicate timing off and promote abnormal heart rhythms, says Bhatnagar. Nicotine has also been implicated in stoking inflammation in heart and lung tissue, says Laura Crotty Alexander, a pulmonary biologist at the University of California, San Diego in La Jolla.

Some researchers think that nicotine has only a small effect on heart health. "Nicotine is a minor player with respect to smoking-induced cardiovascular disease," says Benowitz. He points to studies of snus – a chewable tobacco product that is popular mainly among men in Sweden and is gaining traction elsewhere

– which do not generally show a detectable rise in heart problems among people who use it. However, some studies have suggested that a heart attack or stroke is more likely to be fatal for someone who uses snus[1], and another found that stopping snus use after a heart attack reduced subsequent short-term mortality[2]. This suggests that nicotine could be more harmful to someone with underlying cardiovascular disease, Benowitz acknowledges. And in January, a study suggested that smokeless tobacco increases the risk of peripheral artery disease to a similar extent as does cigarette use[3].

The method of nicotine delivery might also affect its impact. Smoking and vaping both deliver a concentrated hit; nicotine patches, which are used by some people to help them quit cigarettes, provide a more gradual dose.

This could be an important difference. The nicotine hit from smoking and vaping might produce more noticeable spikes in blood pressure. Repeated over time, this could increase the stiffness of arteries and increase pressure on the heart. "Nicotine patches and gum are not the same as taking a drag on a cigarette," says Bhatnagar. "You need that hit, and that's the hit that causes the cardiovascular issues."

Cancer suspicions

Cigarette smoke is rich in tumour-promoting substances, including arsenic, aromatic amines, benzene, ethylene oxide, formaldehyde and PAHs. Evidence for nicotine to join that list of direct human carcinogens is limited.

In vivo animal studies of nicotine exposure have returned mixed findings on the compound's link with cancer. There is evidence that nicotine inhibits apoptosis – the process by which cells self-destruct, which is an important guard against tumour formation – in cancer cells by binding to cholinergic receptors. Nicotine also ramps up the formation of new blood vessels, which can supply nutrients to a hungry tumour.

Nicotine's ability to drive inflammation might also be of note. Most immune cells have receptors that nicotine can hack to sabotage T cells, inhibit antibody formation and interfere with immune messaging. "Someone chronically exposed to nicotine might have chronic inflammation," says Goniewicz. "There is speculation that it might contribute to increased risk of cancer." A 2021 study that examined the impact of nicotine on mouse models of metastatic breast cancer concluded that chronic exposure to nicotine encouraged the spread of tumours by ramping up the amount of neutrophils, a type of white blood cell[4]. "High levels of neutrophils are damaging," says Robert Tarran, a physiologist at the University of North Carolina at Chapel Hill.

The evidence is not unanimous, however, and there is little known about how this relates to people. "Some animal models have found that nicotine does promote cancer," says Benowitz, "but the evidence, for me, is not convincing in tying it to cancer in humans." A 2009 study of long-term nicotine replacement therapy – specifically, a nicotine gum – found no effect on cancer risk[5], although nicotine exposure from gum is lower than would be expected from vaping or snus. Any connection between nicotine and human cancers remains unclear. "From animal and cell studies, yes, nicotine is doing something," says Goniewicz. "How this translates into a risk for the user, we don't know."

A developing problem

The strongest evidence against nicotine relates to its impact on brain development. Activation of acetylcholine receptors helps to regulate brain development and growth. Nicotine binds to these receptors and can therefore interfere with this process. It has been shown that nicotine is responsible for up to almost 50% of the overall impact that tobacco smoke has on brain circuitry development in male rats[6].

Nicotine subtly changes neurons in addicted adults, but its impact is greatest in the developing brain, where circuitry is less mature. Exposure in the womb is an independent risk factor for developmental disorders, such as attention deficit hyperactivity disorder, says Kjersti Aagaard, a maternal-fetal physician at Baylor College of Medicine in Houston, Texas. The brain of a developing fetus or neonate could be especially vulnerable. "No amount of nicotine is known to be safe in pregnancy. None," Aagaard says. "If you are exposed to nicotine in the womb, there could be lifelong consequences."

"If you are exposed to nicotine in the womb, there could be lifelong consequences."

Nicotine exposure in the womb is associated with a higher risk of addictive behaviours in adulthood. Babies could also be exposed to nicotine while breastfeeding. A study last year reported that when female mice were exposed to nicotine, they passed the compound to their pups in their breast milk, and these pups experienced long-lasting behavioural changes[7].

Beyond just neurological impacts, some epidemiological studies – but not all – have linked the use of e-cigarettes during pregnancy with higher rates of preterm and low-birthweight deliveries compared with pregnancies in which the mother abstained from all tobacco products[8], Aagaard says. This in turn brings more risks for children, she adds, such as a greater risk of developing metabolic disorders.

The UK National Health Service describes e-cigarettes as safer than smoking for pregnant women, but it notes that there is little research to support the safety of e-cigarettes beyond that. It recommends pregnant women use nicotine patches and gums to stop smoking.

Nicotinic acetylcholine receptors are involved in forming brain circuits during childhood and adolescence. The brain's prefrontal cortex, responsible for marshalling judgement, impulsivity and risk-taking, does not fully mature in people until their early twenties. There is a strong suspicion that nicotine can throw a spanner in the works throughout this time – a particular concern given the growing popularity of vaping among young people. But the effects of e-cigarettes on teenage brain development is yet to be made clear. "Nicotine is definitely harmful to the developing adolescent brain in animals," Benowitz says. "In humans, it is harder to establish."

Before the advent of e-cigarettes, there was less interest in finding an answer to this question – there are already more than enough good reasons to not take up smoking. The growing popularity of vaping has provided fresh impetus, but also represents an opportunity for scientists. Research into the impact of nicotine on people's health has long been held back by difficulties in isolating the effects of this one molecule from all the other components of cigarette smoke. "We never had a clean nicotine delivery product that would be used recreationally for long periods," Goniewicz says. Now, thanks to e-cigarettes, researchers do.

This continuing population experiment, combined with a growing number of cell and animal studies, could begin to dissipate the fog surrounding nicotine's impact on health. "I've been more and more surprised at the changes I'm seeing when I expose cells to nicotine," says Crotty Alexander. "We've underplayed the role that nicotine has in the health effects of tobacco products."

Anthony King is a science writer in Dublin.

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Dementia Can Unleash Creativity

Frontotemporal dementia can release the creative potential of the brain's visual areas

By Robert Martone

In some people, neurological conditions can set loose a torrent of new imaginativeness as if opening some mysterious floodgate. Migraine and epilepsy auras may have influenced a long list of artists, including, some scholars speculate, Pablo Picasso, Vincent van Gogh, Giorgio de Chirico, Claude Monet, Georges Seurat and Lewis Carroll. Traumatic brain injury can result in original thinking and newfound artistic drive. Emergent creativity is also an occasional feature of Parkinson's disease.

This burst of inspiration is especially true of frontotemporal dementia (FTD). Although a few rare cases of FTD are linked to improvements in verbal creativity, such as greater poetic gifts and increased wordplay and punning, enhanced creativity in the visual arts is an especially notable feature of the condition. This fascinating side effect indicates that the potential to create may rest dormant in some of us, only to be unleashed by a disease that also can cause a loss of verbal abilities.

Emergence of a vibrant creative spark in the face of devastating neurological disease speaks to the human brain's remarkable potential and resilience. A study published in *JAMA Neurology* by researchers at several institutions, including the University of California, San Francisco, examines the roots of this phenomenon and provides insight into a possible cause. Neurologist Adit Friedberg of U.C.S.F. and her colleagues found that as specific brain areas diminish in people with FTD, they release their control of other regions that support artistic expression.

FTD is relatively uncommon—affecting about 60,000 people in the U.S.—and is distinct from Alzheimer's, the far more prevalent form of dementia in which memory deficits predominate. FTD is named for the frontal and temporal lobes of the brain, the two regions that sustain the most damage from this disease. Not every person with FTD has the same pattern of neuron loss in these areas; there are several variants. For example, degeneration in the temporal lobes, which are the seat of language in the brain, leads to difficulties in producing and understanding written and spoken communication. Some people have impaired speech production; others may have trouble understanding word meanings.

People with FTD also experience degeneration in the frontal lobes, which typically engage in a suite of functions related to social behavior, empathy, planning and decision-making. Impairment there can lead to poor judgment and difficulty understanding the perspectives of others. The frontal lobes are involved in the complex interplay of brain areas that supports our social behavior, helping to balance baser desires and urges with an understanding of social norms and morals. In a healthy brain, the frontal lobes' activity can inhibit activity in other regions. This interchange is how the brain counters, for instance, the impulse to use rude language with the recognition that such responses can cause offense. Researchers suspect that in those with FTD, damage to the frontal lobes impairs the ability to suppress other brain activity, and their behavior becomes disinhibited and socially inappropriate.

The *JAMA Neurology* study suggests that, in a similar way, the loss of temporal lobe activity somehow disinhibits artistic creativity in some individuals. The researchers reviewed the medical records of 689 people with FTD or related disorders, looking for evidence of new or significantly increased or altered artistic expression. In total, they found this change in 17 people—2.5 percent of their participants. Most of these individuals painted, although some drew, sculpted, made pottery, crafted jewelry or quilted. FTD can sometimes be linked to certain genes, but no genetic cause of FTD was identified in this group. Most in this artistic group had forms of FTD in which language impairment was predominant, suggesting that FTD significantly affected their temporal lobes.

Researchers then selected people to compare with this artistic group. One set included FTD patients who were similar to the artists in many ways (including their diagnosis, age and sex) but did not exhibit an emergence of visual artistic creativity. An additional group matched the artists demographically (in age, sex, education, and other factors) but did not have any form of dementia or other serious health concern.

The research team used magnetic resonance imag-

Illustration by Thomas Fuchs

Robert Martone is a research scientist with deep expertise in neurodegeneration, neuro-oncology, biomarkers and drug discovery. He is currently associate director of the Lab-Corp Biomarker Solution Center, supporting research on neurology biomarkers.

ing to examine the brains of the people in these three sets. Significantly, the scans revealed that people with FTD had reduced volume in their left temporal lobe—an area important for speech production—compared with that of healthy individuals. The atrophy was more pronounced in the artistic group than in those without artistic tendencies.

The scientists also found that some brain areas were more active when there was less activity in other areas. In particular, healthy people with less activity in the temporal lobe regions affected by FTD had more activity in their dorsomedial occipital lobe, a region involved in visual association. This finding implies that impairment of the temporal lobes by FTD could enhance this visual area. Further, among the visual artists with FTD, the greater the volume of the dorsomedial occipital lobe, the greater the volume of the portion of the motor cortex that controls movement in the right hand.

Taking the evidence together, the researchers concluded that this disease's effects on the temporal lobe may result in less control over the brain region that generates visual associations. In consequence, the creative drive is unleashed. Meanwhile the increased volume of the brain area that controls the right hand might reflect the use of that hand in creating art.

The researchers tested these ideas by observing brain changes in one person as her FTD progressed and creativity emerged. Positron-emission tomography scans measured the amount of energy being used by different regions of her brain. The scans revealed that as the woman's dementia progressed, her frontal and temporal lobes became significantly less active—and the areas involved in visual association became more active.

The study suggests that in a healthy brain, the temporal lobe directly or indirectly inhibits activity in the dorsomedial occipital lobe, which supports visual association. But why would a part of the brain involved in verbal processing suppress visual regions? From these findings, we can infer a reciprocal or even competitive relation between our verbal abilities and visual artistic creativity.

This insight is at the heart of a hypothesis regarding how our brain has changed over the course of human evolution: the superior visual perception hypothesis. Vision demands a lot of our brain's computational capacity—so much that we often close our eyes to concentrate on what we hear, whether it is music, speech, birdsong or crashing waves. According to the evolutionary hypothesis, when our species first began to develop language, the brain diverted computational capacity from visual processing to bolster this new activity.

For example, visual processing helps us comprehend gesture, a nonverbal form of communication that probably preceded our use of verbal language. Computational tasks that supported the production and interpretation of gesture were also relevant to speech, and so as we became more adept at language, gesture lost its primacy in communication. The brain regions responsible for gesture could have been taken over by those used in speech through an evolutionary process called exaptation, wherein parts of an organism take on different or completely novel roles.

This hypothesis may explain why areas involved in verbal processing might somehow tamp down activity linked to visual thinking. The FTD research suggests this evolutionary process is, in a sense, undone in the artists with dementia.

Brain injury and neurodegenerative disease often have tragic consequences. It is therefore remarkable that these conditions can have a seemingly positive effect such as enhanced creativity—and this finding can help us understand the origins of innovation. Creativity is part of humanity's essence and distinguishes us in some ways from our hominin relatives. Is it possible that an artist is hidden in each of us, awaiting an accidental emergence?

Creativity is a complex behavior that requires several elements, including the capacity for divergent and symbolic thought, persistence despite uncertainty, skill in execution and the ability to evaluate one's creations. When considering the burst in artistic activity sometimes seen in people with FTD, all these factors should be weighed. In general, patients with FTD perform poorly on tests of divergent thinking, suggesting either that the subset of people with the condition who become artists is quite distinct from others who have it or that different aspects of creativity are somehow enhanced in the FTD artists. Other studies have found that aesthetic judgment is retained in FTD, allowing affected people to evaluate the strength of their finished artwork, although many struggle to recognize emotional content in visual art.

Past research has also demonstrated that creativity emerges when we limit our self-critical thinking. In those with FTD, a lack of self-censorship may contribute to socially inappropriate behavior, for example, but it might also mean an artist's "inner critic" is less vocal. Yet another facet of artistic success is practice. FTD is often accompanied by perseverative behavior in which people repeat the same actions or statements or become mentally stuck in an idea or behavior. Some scientists have proposed that the FTD artist benefits from the combination of behavioral disinhibition and repetitive practice. Indeed, that could also help explain the literary output of poetic people with FTD, who, unlike visually artistic people with the condition, have been spared significant losses to the temporal lobes' language areas.

Still, none of these ideas fully explains the flourishing of creative behavior in some people with FTD. The authors of the *JAMA Neurology* study emphasize that the FTD artists were only a small percentage of the total number of people with this dementia in their study group. Other factors, such as an artistic predisposition and circumstances or an environment conducive to creative pursuits, may be important.

The FTD artist may help us understand creativity. Studies of such individuals can reveal the subtle interplay among brain regions that manifests in remarkable behaviors. The complexity of creativity makes it even more incredible that such ability can be a consequence of neurodegeneration. Ultimately these findings are a humbling reflection of the human brain's adaptability and seemingly endless capabilities. SA

Is E.T. Eavesdropping on Us?

Cell-phone towers leak radio waves into space, but the signals will be tough for aliens to detect

By Phil Plait

Ever worry about shadowy forces tapping your phone calls and listening in on your private conversations? Well, astronomers have some good news for you: it won't be aliens with their ears (or whatever auditory sensory organs they have evolved) to the speaker getting into your business—unless they've done a lot better than we have at funding radio astronomers. And even then, they'd have to be *really* close by.

Scientists working on SETI—the search for extraterrestrial intelligence—have long pondered how to detect life outside Earth. Assuming there are technologically advanced aliens out there, they might be trying to communicate with us, or they might just be leaking radio energy into the cosmos by accident. Either way, can we pick up that signal? One way to tackle this question is to turn it around: We know how much energy *we're* broadcasting into space. Given our own level of technology, could we detect such a signal from light-years away? If so, then maybe we can hear extraterrestrials, too.

SETI scientists have focused their efforts mostly on radio waves because they're easy to make; any young technological civilization will figure that out pretty quickly—after all, we did. They can be beamed with a lot of power, have lots of information encoded in them, and can travel easily through the myriad dust and gas clouds littering our local space environment. They're ideal for cross-galactic communication.

This kind of study has been done in the past; research published in the journal *Science* in 1978 looked at our television signals and military radar, the most powerful transmissions we could send into space. At that time radio telescopes could detect those emanations out to 25 and 250 light-years away, respectively. This is a volume of space that encompasses several hundred thousand stars. In the decades since, our broadcast TV signal has waned as we've turned to cable and the Internet to deliver our shows. The days of wondering whether aliens loved *Lucy* as much as we did are behind us, I'm afraid.

But other communication methods are on the rise, and they could prove more fruitful for any aliens looking for another lonely civilization with which to chat. Research by SETI scientists published in the *Monthly Notices of the Royal Astronomical Society* looks at how our cell-phone usage might be detectable from other stars.

David Wall/Getty Images

Without going into too much technical detail, cell phones emit a weak signal that can be detected by a nearby tower, which in turn emits a much stronger signal to send the transmission along. Coverage for a given phone company is divided into small areas called cells, each populated with one or perhaps a few towers that can pick up nearby phone signals.

The signal strength of an individual phone is only a fraction of a watt, but a tower emits a couple of hundred watts—about the same as a bright lightbulb. That's not much, but there are a lot of them. OpenCelliD, an open database of cell locations, has tens of millions of cells listed globally. The total power emitted by cell-phone transmissions can be measured in gigawatts.

What an alien would detect when pointing a radio telescope at Earth depends on more than just the combined signal strength of all those towers, though. The direction the towers transmit in is also important. Most human cell-phone users are located near Earth's surface, so the tower antennae are configured to send their signals parallel to the ground, covering it like lawn sprin-

Phil Plait is a professional astronomer and science communicator in Colorado. He writes the *Bad Astronomy Newsletter.* Follow him on Twitter @BadAstronomer

klers spraying water. If you're on the ground near a tower, you'll get a strong signal from it, but if you're above it, you'll get at best a weak signal.

Tower locations matter as well. There are very few towers in the Pacific Ocean nations, compared with a huge number in the U.S. And there are more towers in the Northern Hemisphere than the Southern, so our alien friends would see a different signal depending on where their home star is located in the sky.

Putting this together, the scientists modeled what aliens would see from hypothetical planets orbiting three nearby stars: HD 95735, Barnard's Star and Alpha Centauri A. All of these are less than nine light-years away, practically in our galactic backyard, maximizing the snooping capabilities of any nosy aliens. The stars are also widely spread in declination (the measure of latitude on the sky), meaning observers in those spots would see how Earth appears from different directions.

The conclusion? If the alien tech is the same as ours—with a radio telescope as big as the 100-meter Green Bank Telescope in West Virginia—our overall cell-phone signal is still far too weak to be detected from any of the three stars. The next-generation Square Kilometer Array, currently under construction in Australia and South Africa, will be more sensitive but still will have only about 1 percent of the sensitivity needed to detect Earth's transmissions from tens of trillions of kilometers away.

If aliens are anything like us, then, we're safe from eavesdropping. Judging from my time spent in airports and other public places, however, a lot of people don't care at all who overhears their calls. I wouldn't go so far as to say I hope aliens abduct them, but I'm not *not* saying that.

What if our galactic neighbors are more advanced technologically? Telescopes detecting interstellar radiation are like buckets set outside in a rain shower: the bigger the bucket, the more water it collects. It's technically feasible to build far larger radio telescopes than we have now. There are even serious proposals to build huge radio telescopes on the moon. These would be far more sensitive than what we have today, perhaps capable of picking up transmissions such as our mobile signals even from interstellar distances.

There's still a chance that extraterrestrials could listen in on our cell-phone conversations, provided they are close enough and are in the right part of the sky.

So there's still a chance that extraterrestrials could listen in on our cell-phone conversations, provided they are close enough, are in the right part of the sky, and have slightly better tech on hand (or tentacle or pseudopod) than we do now. You can decide which part of that last sentence is the most far-fetched, but in any case, that's a lot of ifs. The longest odds are that they're sufficiently close to us; if their home world is 1,000 light-years away, they'll need a telescope the size of a moon to pick up our transmissions. Possible, but a lot of effort.

Still, the scientists note that the number of terrestrial cell-phone towers is increasing, and we get brighter in radio emissions every day. They also plan on expanding their work to include more powerful 5G towers, radar, satellite services, and more to get a better handle on just how loudly we're announcing our presence in the galaxy. Remember, too, that all of this is to solve the more pertinent puzzle of whether *we* can hear *them*. That remains a maybe, an ambiguous and somewhat maddening conclusion. And of course, everything depends on the answer to the biggest question of all: Are they even out there?

If so, E.T., please phone Earth; we're eagerly awaiting your call. SA

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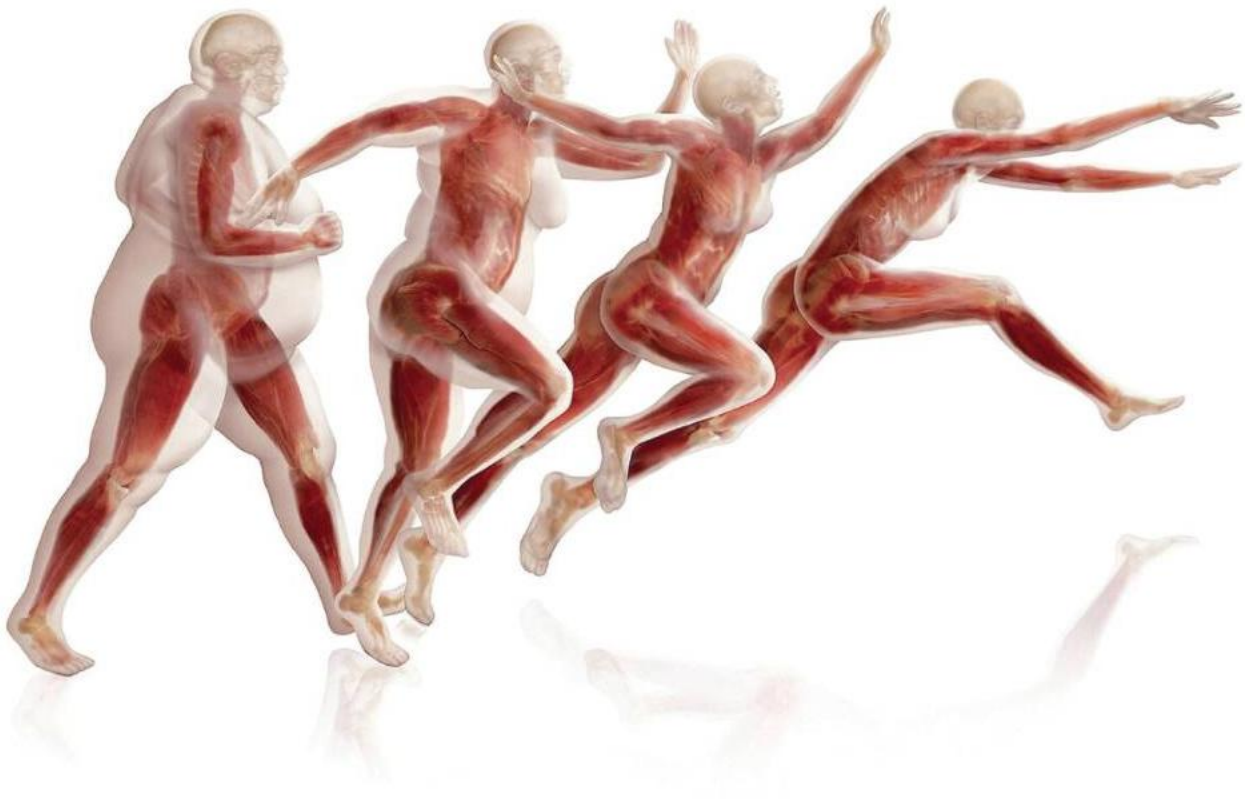

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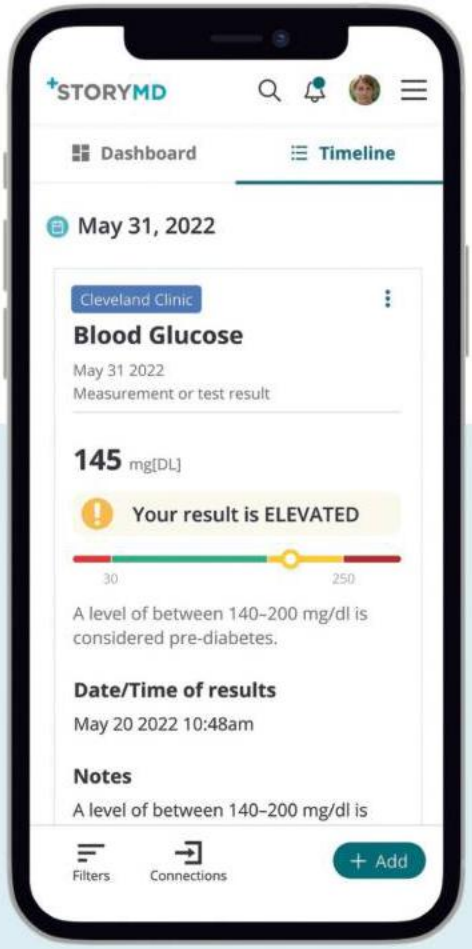

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BREAKING NICOTINE'S CHOKEHOLD

Established nicotine replacement therapies combined with behavioural counselling could offer the best chance of BEATING NICOTINE ADDICTION.

Thicha Studio/iStock/Getty

▲ Smoking cigarettes remains the leading preventable cause of death worldwide.

"Early in my career, I met people who told me they found it easier to quit heroin than cigarettes," says Scott Leischow, research professor in the College of Health Solutions at Arizona State University. "This highlights how profoundly difficult it can be to break the smoking addiction."

Smoking cigarettes remains the leading preventable cause of death worldwide; killing more than eight million people each year, according to the WHO. In the US, the CDC estimated that 12.5% of adults were 'current smokers' in 2020. The CDC also estimated that cigarette smoking cost the US more than $600 billion in 2018 — through the burden of smoking-related diseases, addiction support, and lost productivity from illness and premature death.

Most adult cigarette smokers want to stop, and many can and do quit for good: since 2002 there have been more former smokers than current smokers (CDC, 2022). But the social aspects of smoking and other lifestyle factors can make this a very difficult process. Various activities and tools are available to those who are trying to quit. Nicotine replacement therapies (NRTs), smoking cessation medicines and counselling are the only established, FDA-approved methods for quitting cigarette smoking and tackling nicotine addiction in the US[1].

Many people turn to e-cigarettes to quit their tobacco counterpart, but these are not FDA-approved. They do offer consumers an alternative, cleaner option to smoking tobacco, but also run the risk of keeping people in the nicotine addiction cycle. Long-term data on their effect on health are also lacking. With a history that stretches back almost 40 years, the value of NRTs, smoking cessation medications and behavioural therapy as means for quitting is well-established. While all these methods can help get people away from combustible cigarettes, the end goal of quitting nicotine is a more difficult challenge that should not be ignored.

HOW NICOTINE AFFECTS THE BODY

Cigarette smoke contains more than 7000 chemicals, including 70 carcinogenic substances like arsenic[2]. Heart disease can develop in smokers because of exposure to chemicals like nicotine and carbon monoxide — which, along with other toxic chemicals, can cause irreversible lung damage. Nicotine and other inflammatory chemicals can also lead to diabetes: according to CDC, people who smoke are 30–40% more likely to get type 2 diabetes than people who don't smoke. Although not considered deadly on its own, nicotine can nevertheless have detrimental effects.

Acetylcholine, the most abundant neurotransmitter in the human body, conveys chemical messages between nerve cells in almost every organ. Nicotine is structurally similar to acetylcholine and can bind to acetylcholine receptors in the brain, heart, blood vessels and immune system: it can fundamentally change how the body functions.

Like most addictive drugs, nicotine generates feelings of pleasure and satisfaction by causing the release of dopamine. It also releases glutamate, which is involved in learning and memory; endorphins, which play a role in calming and sedation; and serotonin, which is implicated in mood modulation and appetite.

"Nicotine also affects stress levels and attention. It enhances the action of whatever is going on in the body," says Neal Benowitz, professor emeritus of medicine at the University of California, San Francisco. "In the early morning, nicotine is stimulating like coffee. If you need to concentrate at work, nicotine helps you focus. It is not intoxicating like some other drugs — another reason why it is popular."

Over time, nicotine has progressively less of an effect on receptors that release dopamine and other chemicals. Then, if a person doesn't have a cigarette, they suffer withdrawal symptoms like irritability, difficulty concentrating, depression and stress. The day's first cigarette often provides the best 'rush', and people smoke more heavily over time to replicate that satisfaction.

Cigarette smoke also has other addictive substances which heighten the challenges of quitting. "An enzyme in the brain called monoamine oxidase breaks down certain neurotransmitters like dopamine," says Benowitz.

▲ NRTs, like patches or gums, can reduce the urge for a cigarette and help to prevent withdrawal symptoms.

Andriy Popov/Alamy Stock Photo

Cigarette smoke includes compounds that inhibit monoamine oxidase, so when the nicotine releases dopamine, it stays around longer in regular smokers.

There are also genetic elements to addiction, so certain people are more susceptible to nicotine addiction than others. Some genes can even alter the efficacy of drugs like varenicline, which are designed to help people quit cigarettes by reducing cravings[3].

BEYOND BIOLOGY

The familiarity of certain actions and social occasions also feeds the addiction cycle — if someone always smokes while driving, they associate sitting in a driver's seat with lighting a cigarette. Repetitive actions are soothing — and even watching someone strike a match can trigger a former smoker.

"The rituals associated with smoking are powerful," says Leischow. "It's a classic interplay of biological and socio-psychological drivers." The pairing of impulsive behaviours with a dose of nicotine and the resulting dopamine hit takes tight hold. "Smokers trying to quit say they feel like they're giving up a friend," he adds.

To successfully quit smoking, therefore, requires more than just attending to physical effects on the body. "The reality is that the actual craving for a cigarette lasts only a few minutes," explains Leischow. Distraction techniques are vital, and tailored counselling can help people to get past the most intense time. Cognitive behavioural therapy, which can help people change the way they think about and behave towards a specific problem, has proven successful in smoking cessation. Open group therapy sessions are also very useful because they provide people with a supportive network and a safe, honest space for discussion and advice. Leishow advocates that a range of options be available to those wanting to quit smoking.

COMBATING NICOTINE ADDICTION

NRTs are a long-established, FDA-approved method to help smokers break free from cigarettes. They come in a variety of forms, including gums, lozenges, and — most recently — mouth sprays. Oral inhalers provide the most similar experience to smoking a cigarette out of all NRTs.

Many NRTs are available without a prescription because they slowly deliver low levels of nicotine and are therefore less likely to be addictive. Short-acting NRTs, like gum or lozenges, can reduce the immediate urge for a cigarette. There are also long-acting prescription medications, like bupropion and varenicline, which bind to nicotinic receptors in the body. They prevent withdrawal symptoms and stop the feeling of reward that comes from smoking a cigarette. NRT patches have a similar long-term effect.

Many people use a combination of both short and long-acting NRTs when trying

Fiordaliso/Moment/Getty

▲ When quitting smoking, distraction techniques and tailored counselling can help people to get past the most intense time.

to quit smoking. Such products are likely needed for a limited time because they do not reinforce nicotine addiction as e-cigarettes do.

Quitting becomes more comfortable with NRTs. But though they reduce withdrawal symptoms, they only address the biochemical aspects of smoking. "A smoking cessation treatment that works with 100%, or even 50% of people simply doesn't exist," says Leischow. To improve the chances of success, the 'ritualistic' aspects of smoking also need to be addressed. "Research shows that pairing varenicline or a combination of NRT medications with behavioural support is the most effective route."

Smoking quit rates can increase in those offered NRTs, medications or both plus some form of behavioural therapy[5]. Behavioural counselling — in person or over the telephone — has been shown to increase the chances of a person quitting smoking and adhering to it by 10–20%, compared to those given medication alone. In-person therapies work better than written or self-help information, especially when used with 8 to 12-week supplies of pharmacotherapy to increase the long-term success of quit attempts.

"One method I use is a 'delayed quitting' approach," says Benowitz. "I'll say: it's OK not to quit now. Take varenicline or patches and these will reduce your urge to smoke — each cigarette will be less satisfying to you. Reduce your cigarette use, and it'll be easier to quit in a month from now." Benowitz also highlights the value of illustrating health risks, for example via lung function tests or telling the patient about carbon monoxide exposure. "These techniques help show that while a person might be feeling OK now, it would be wise to quit before chronic lung disease kicks in."

CAUTION NEEDED WITH ALTERNATIVES

The need for harm reduction and cleaner alternatives to tobacco means that e-cigarettes have increased dramatically in popularity. E-cigarettes contain far fewer chemicals overall than cigarette smoke, but they are a relatively new technology, and longitudinal data regarding their safety are not yet available[4]. Researchers are airing significant concerns around young people who are vaping, having never smoked before.

> "RESEARCH SHOWS THAT PAIRING VARENICLINE OR A COMBINATION OF NRT MEDICATIONS WITH BEHAVIOURAL SUPPORT IS THE MOST EFFECTIVE ROUTE."

Even though vaping may be a useful tool for helping some tobacco smokers quit[3], it holds the risk of getting 'trapped' in the middle stage: still addicted to nicotine despite successfully quitting cigarettes.

"E-cigarettes are popular because the overall effect is very similar to cigarettes," says Leischow. "The risks of using e-cigarettes are significantly lower than a combustible cigarette. But does it mean that they're safe? I would never call an e-cigarette safe."

INFORMATION AND SUPPORT ARE KEY

Even when a person manages to stop smoking, the long-term effects of nicotine on the body can increase the likelihood of relapse. For example, when someone experiences a stressful life event, the cravings for nicotine can return because the body knows it will help elevate dopamine and other neurotransmitters to make the person feel better.

"Humans often look for short-term benefits — we make poor decisions for immediate gains, rather than thinking long term," says Leischow. Integrating behavioural therapy into quitting can help smokers learn techniques to prevent relapse. Smoking cessation is often a two-stage process: quitting cigarettes and quitting nicotine altogether. NRTs and medications help with the withdrawals when cutting out tobacco. Along with behavioural therapies, these can carry the person through to fully quitting nicotine. Leischow emphasizes the need to help people fully understand their biological responses to nicotine and how behaviours feed into addiction. "Providing people with the right tools can help them understand and break the addiction cycle." ■

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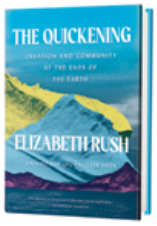
HALEON

NONFICTION

Nurturing Uncertainty

What can Antarctica's "doomsday glacier" teach us about community?

By Rachel Riederer



The Quickening: Creation and Community at the Ends of the Earth by Elizabeth Rush. Milkweed, 2023 ($30)

As writer Elizabeth Rush prepares for her two-month expedition to Antarctica, on an icebreaker ship staffed with scientists from around the globe, she is focused on danger and on scarcity. The researchers are traveling to the Thwaites Glacier, a behemoth whose potential collapse could dramatically reshape the time line and scale of sea-level rise. "Will Miami even exist in a hundred years?" Rush muses. "Thwaites will decide." The glacier juts out into the Amundsen Sea, which is inaccessibly frozen over except for a few weeks in January and February. Rush solicits advice about what to pack for this precious window of data gathering—treats for when the ship's galley runs short of fresh produce; work gear that will fit her female form better than the government-issued versions—and about how to stay safe amid the extreme isolation of the voyage. It seems to be the start of a classic adventure tale.

In some ways, it is. Rush structures the journey as a four-act play, complete with a cast of characters listed before the first chapter. In act 1, the group members prepare for departure, savoring their last chances to have a drink or go for a terrestrial jog. Act 2 brings them to literally uncharted waters, where they take sonar readings to map the ocean floor and test a submarine to see if it can be successfully launched. They take inflatable boats from the relative safety of the giant ship onto a tiny island, where they follow a penguin trail and scour the beaches for penguin bones. Throughout, Rush offers keen observations of the fieldwork and lyrical depictions of the setting, in turn menacing and ethereal. In a moment of great danger, "the bergs are many, lavender and faceted, when the air is full of floating ice crystals."

But Rush is not at the bottom of the world to conquer, survive, test her mettle, compete or plant a flag. Her journey, woven through the story of the voyage, is a much quieter one: to explore her desire and uncertainty about becoming a parent. Rush is 35 years old when she joins the expedition and worried about the closing window of her fertility. Pregnant people are not allowed on the long and dangerous cruise, and so joining the trip means that she and her husband have delayed trying to start their family by a year. Alongside the dramas on the ship—including treacherous storms and a medical evacuation—she reckons with an interior question that is increasingly familiar: Is it ethical to bring a child into a world so threatened by climate collapse?

As dozens of climate researchers head toward the "doomsday glacier," this question is thrown into especially sharp relief. Resonances arise organically among the potential futures of Antarctica, the challenges of predicting the climate system, and motherhood. All are uncertain, and all are attached to unforgiving deadlines. "I know what it feels like to fear that there may not be many meaningful strategies left," Rush writes. In another instance, "there is a clock, and it is ticking." She could be talking about her own fertility, the window of time in which humanity must move away from fossil fuels or the team's need to gather what data it can before the Amundsen Sea freezes it out.

Rush's preoccupations guide the course of the inquiry, but her view of both the ambivalence of parenthood and the perception of Antarctica is one of many. Her shipmates are co-narrators, with snippets of their interviews peppered throughout her prose. A marine geophysicist, for instance, details the extensive child care arrangements that made it possible for her to do the trip. When everyone gathers on the deck as the first iceberg comes into view, Rush likens the ice to "whipped meringue piped into a lopsided point." For others, it evokes the geological shapes of Utah, a ski slope or the movie *Happy Feet*.

By collecting and highlighting a multitude of voices, Rush explicitly works against the classic storylines that dominate Antarctic history: "Amundsen's conquest of the pole, Scott's death eleven miles from One Ton Depot, Shackleton's miraculous return, Douglas Mawson shooting and eating his sled dogs." Those tales center on the heroics of an individual (who is always a man and almost always white, Rush notes). *The Quickening* instead offers an exploration story that is also a literature of community, as attentive to the cooks and the marine techs as it is to the scientists whose work they support.

Rush herself pitches in with the data collection—sometimes helpfully and once, memorably, to disastrous effect—and she comes away with a fresh view of the work of scientific research, something she begins to understand as "a deeply communal act." Ultimately Rush determines that the work of parenting, like the floating village of people studying the glacier, is paving the way for other, better futures.

Rachel Riederer is a writer and editor focusing on climate and culture. She lives in New York City.

Illustration by London Ladd

FICTION

Revenge of the Land

Powerfully unsettling fiction from Indigenous writers

Atrocities against people and land haunt these present-day stories.

Bijaya Gurung/500px/Getty Images

Although they are mostly set in the present, the past haunts these unsettling dark fantasies and straight-up horror tales from Indigenous authors. Mining rich strata of poisoned history and blood-soaked land, the writers summon an exhaustive array of ghosts, wolves, Wendigo spirits, human eaters, conjure women, and petroglyphs willing to exact revenge if you scratch them with your car keys. Throughout the 26 stories, contemporary American life is a threadbare bandage soaked through with the gore of the wound it never truly covers or heals.

In Rebecca Roanhorse's standout "White Hills," an Instagram influencer's #blessed life is threatened by her casual mention of Native American ancestry. Perhaps the collection's most visceral story, it examines eugenics and phrenology-based racism and builds to scenes of brutal horror. Nick Medina's piercing "Quantum" likewise turns on questions of genetics, when the mother of two young children from different fathers learns, after blood testing, that one qualifies as a tribal member, entitled to casino money, while the other doesn't. The true terror in both stories comes from the protagonists' desperation to either claim or hide Indigenous lineage.

Never Whistle at Night: An Indigenous Dark Fiction Anthology
Edited by Shane Hawk and Theodore C. Van Alst, Jr. Vintage, 2023 ($17, paperbound)

In story after story, whether in subdivisions or scrub grass, the protagonists find the past—"the old ways"; "country nonsense"—seeping into their now. In one, the ghost of General Custer's widow physically attacks the narrator with "the strength of death." Spirits take revenge, old truths suddenly get proven again, and professors—in Mathilda Zeller's "Kushtuka" and in Amber Blaeser-Wardzala's scathing "Collections"—are eager to mount Native American tools (and worse) on their walls, as if their utility has passed.

Ownership of stories, and the way they change in the telling, is a pressing concern. In Darcie Little Badger's "The Scientist's Horror Story," a geologist regales scientist friends at a convention with his own tale of searching a New Mexico ghost town for whatever has been transforming victims' genomes into "a nonsensical pattern of nucleotides." (One listener takes notes on holes in the plot.)

After building to a classic ghost-story climax, the speaker somewhat sheepishly agrees that it was all made up, just a spooky laugh, letting his audience off the hook from feeling obliged to think about such things—or, by implication, the blood that seeps through the bandage.

—Alan Scherstuhl

IN BRIEF

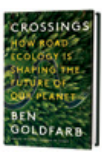
Of Time and Turtles: Mending the World, Shell by Shattered Shell
by Sy Montgomery. Illustrated by Matt Patterson. Mariner Books, 2023 ($28.99)

The movie portrayals of turtles as ultrachill surfers or pizza-ordering elite fighters have little in common with the richly understated lifestyle Sy Montgomery chronicles during the year she spends volunteering at a local turtle sanctuary. There's abundant drama in the high-stakes field trips: rescuing the victims of hit-and-runs, unearthing freshly laid eggs, releasing rehabilitated "herps" into the wild. But it's Montgomery's heart-tugging conversations with teammates and her commitment to helping an octogenarian named Fire Chief that reveal turtles to be perfect conduits for meditations on aging, disability and chosen family. *—Maddie Bender*

Land of Milk and Honey: A Novel
by C Pam Zhang. Riverhead Books, 2023 ($28)

When a thick layer of global smog causes crop failure, extinctions and famine, a struggling cook eagerly accepts an offer to work as a private chef for an insular community of elites perched on a mountaintop high above the choked atmosphere. Though ensconced in environmental privilege and culinary abundance, she soon discovers that her new post comes with troubling expectations. As her cryptic employer takes drastic measures to secure the community's future, she must choose whether to remain there or break free. Writer C Pam Zhang's lush but precise descriptions and inventive premise create a thought-provoking fusion of the sensory and the speculative. *—Dana Dunham*

Crossings: How Road Ecology Is Shaping the Future of Our Planet
by Ben Goldfarb. W. W. Norton, 2023 ($30)



Roads may be connective for humans and commerce, but they're distinctly disruptive to ecosystems and wildlife, writes journalist Ben Goldfarb in this swift and winding ride through the science of road ecology. He covers pumas, passages and pavement with equal parts mirth and earnestness, resulting in a surprising reflection on what we owe to nature. Many readers came away from Goldfarb's first book, *Eager,* as newly minted beaver fans; don't be surprised if you finish *Crossings* as an evangelist for road ecology. At the least, the roadkill you spot along the highway will never look the same.

—Tess Joosse

Child Labor Laws Are under Attack

Efforts to weaken labor protections are linked to the social Darwinist notion that people are inherently unequal

By Naomi Oreskes

"If there is any matter upon which civilized countries have agreed …, it is the evil of premature and excessive child labor." So said U.S. Supreme Court Justice Oliver Wendell Holmes, Jr., in 1918, when Americans were waging a fierce battle over the employment of young children. More than a century later the argument rages again. In recent months 14 states have introduced or passed laws weakening labor protections for minors, even in notoriously dangerous industries, such as meatpacking. Nonenforcement of existing laws that limit the hours and types of work that can be performed by kids is also on the rise. This past year the number of minors illegally employed—including children as young as 13—increased by 37 percent.

Holmes's comments remind us that there's a long and baleful story behind contemporary efforts to bring back child labor. Although few, if any, of today's advocates of weakening child labor protections would admit it, the defense of child labor is historically linked to social Darwinist beliefs that people are not equal and do not deserve an equal chance in life.

Holmes made his comment in a 1918 dissent to a Supreme Court decision that overturned a federal statute meant to limit child labor. Child labor was commonplace back then: according to one estimate, between 1890 and 1910, nearly 20 percent of all American children 10 to 15 years old worked in industrial settings. Some forms of work—such as cleaning narrow chimneys or crawling under machinery to recover lost objects or bits of fabric—were considered particularly suitable for children as young as five or six because of their small stature.

The overall trend—in "civilized" nations, as Holmes put it—was toward keeping children out of the workplace to enable them to go to school and improve their lives through education. In the U.S., this was mostly achieved through state law. But manufacturers criticized these laws as creating an unlevel playing field: to them, any state limit on child labor would disadvantage them relative to competitors in states without such limits. One manufacturer in South Carolina even stated that a proposed bill prohibiting the employment of children under age 12 could be called "a bill to discourage manufacturing in South Carolina." To level the playing field, Congress passed two federal laws. When the Supreme Court overturned these laws on constitutional grounds, it was an obvious choice to amend the Constitution.

It is a conspicuously forgotten piece of American history that in 1924 the U.S. Congress passed the Child Labor Amendment, which granted Congress the power to "limit, regulate, and prohibit the labor of persons" under age 18. Had it been ratified by the states, it would have been the 20th Amendment to the Constitution. But business leaders mobilized against it.

The business effort relied heavily on denying the facts of child labor and propagating false, misleading and disingenuous arguments. One example comes from the industry newsletter *Southern Textile Bulletin,* whose editor took out advertisements claiming that the proposed amendment would hinder boys from doing farm work and girls from doing the dishes. This was misleading because the amendment simply authorized Congress to pass a federal law (but did not stipulate what would be in it); existing state laws had almost always exempted agricultural labor; and even the most zealous reformers had no objection to household chores.

Another example came from the National Association of Manufacturers (NAM)—at the time the nation's largest trade association—which insisted (without evidence) that "the nature and extent of the work done by children is grossly exaggerated." The group claimed the amendment was a power grab to enable Congress to control the "labor and education of all persons under 18 to an extent not now possessed by any State of the Union." Both these claims were false. The facts of child labor were well documented, and the amendment said nothing about education.

NAM also made a slippery slope argument: it claimed that in time the government would use the amendment to expand its power even more. And it engaged in red-baiting by insisting that the proposed 20th Amendment was "socialistic in its origin, philosophy and associations." One pamphlet issued by NAM noted that the 1922 Fourth Congress of the Communist International had declared its intent to abolish all wage labor by children under age 18, suggesting that if communists wanted to eliminate child labor, then Americans who advocated the same must be communists, too. Senator William H. King of Utah declared the proposed amendment to be a "communistic, bolshevistick scheme."

These claims were rooted in noxious ideas about inequality and opportunity. Many defenders of child labor were social Darwinists who believed people were inherently unequal. They associated child labor laws with socialism because the laws enforced assumptions of equality they rejected—such as that all children should go to school. They argued that the "natural place" of some children (like some adults) was in factories. Typically this referred to children of immigrants, particularly Catholic and Jewish immigrants from southern and eastern Europe.

Child labor was finally brought under control in 1938, when Congress passed (and the Supreme Court upheld) the Fair

Naomi Oreskes is a professor of the history of science at Harvard University. She is author of *Why Trust Science?* (Princeton University Press, 2019) and co-author of *The Big Myth* (Bloomsbury, 2023).

A child laborer works at a cotton mill in South Carolina in 1908.

Gado/Getty Images

Labor Standards Act, which, among other things, banned child labor in hazardous trades, including most jobs in coal mining, forest firefighting and meatpacking. The legislation, combined with improved adult wages (so families felt less need to send kids to work) and increased compulsory school attendance, decreased child labor in industrial settings dramatically.

Today we are seeing many old arguments being revived to reverse a century of social progress. Child labor is a case in point. Advocates of weakened protections for children claim that the states—not the federal government—should decide; that attempts to regulate the workplace represent a federal power grab; and that the defenders of strict limits on child labor are socialists trying to (unreasonably) level the playing field. Underlying these arguments is the same ideological framework that prevailed in the 1920s: an anti-government ideology pushed by business leaders who resent government regulation broadly and want the "freedom" to pollute the atmosphere, operate dangerous workplaces and rob immigrant children of their chance to succeed in school and beyond. SA

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1973 Polywater's Final Exit

"The long-standing controversy over the existence of a superdense, polymeric form of water is apparently over. The argument began when Boris V. Derjaguin and colleagues at the Soviet Academy of Sciences observed that certain samples condensed in fine capillary tubes represented a new, stable form of water with a density almost one and a half times that of ordinary water and a molecular structure that could only be described as polymeric. Subsequent investigations in the U.S.S.R., Britain, Germany and the U.S. argued that the anomalous properties could be explained by impurities. Derjaguin has now reported that recent measurements by his group have revealed that their samples invariably contain trace impurities."

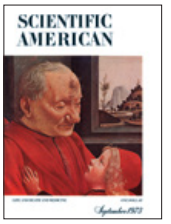
Drunk Intestines

"Alcohol is manufactured in the human intestine by microorganisms. The amount of pure ethyl alcohol (the potable kind) produced daily is about one ounce. Ethyl alcohol ingested by a human, or produced in the intestine, is carried to the liver. In the liver 80 percent is broken down by alcohol dehydrogenase; the remaining 20 percent is possibly metabolized by another enzyme, catalase. It is the efficiency of the process that so long masked the production of alcohol in the intestine. The microorganisms that produce it remain unknown."

People with auto-brewery syndrome produce much more alcohol daily and may seem intoxicated even though they haven't been drinking.

The Jesus Lizard

"The basilisk lizard of Mexico and Central America has a unique ability: it can walk on water. In some areas this ability has earned it the name *lagarto Jesus Cristo*—the Jesus Christ lizard. Joshua Laerm of the University of Illinois photographed the animals with a high-speed camera. As the basilisk picks up speed, it twists the lower half of its body from one side to the other and thrusts each leg backward and to the side. The result is a rapid waddle, necessary to push itself ahead with maximum force and retract each leg from the water with a minimum of resistance."



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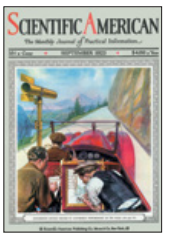


1923

1873

1923 Sixteen Ohms of Malaria

"'You have sixteen ohms of malaria,' exclaimed the man at the rheostat, to a member of the *Scientific American* staff who has been investigating the much-disputed Electronic Reactions of Abrams, a method of diagnosis and treatment developed by Dr. Albert Abrams of San Francisco. There are ERA practitioners throughout the country. Remarkable cures are said to be effected, including cases of cancer. But there are many doubters in and out of medical circles. The public, looking on, remains in a quandary."

ERA was a huge medical hoax. It held that diseases have a unique vibration rate that could be sensed from a drop of blood, or a handwriting sample, and treated, all with Abrams's sealed electronic boxes.

1873 Superhuman Insects

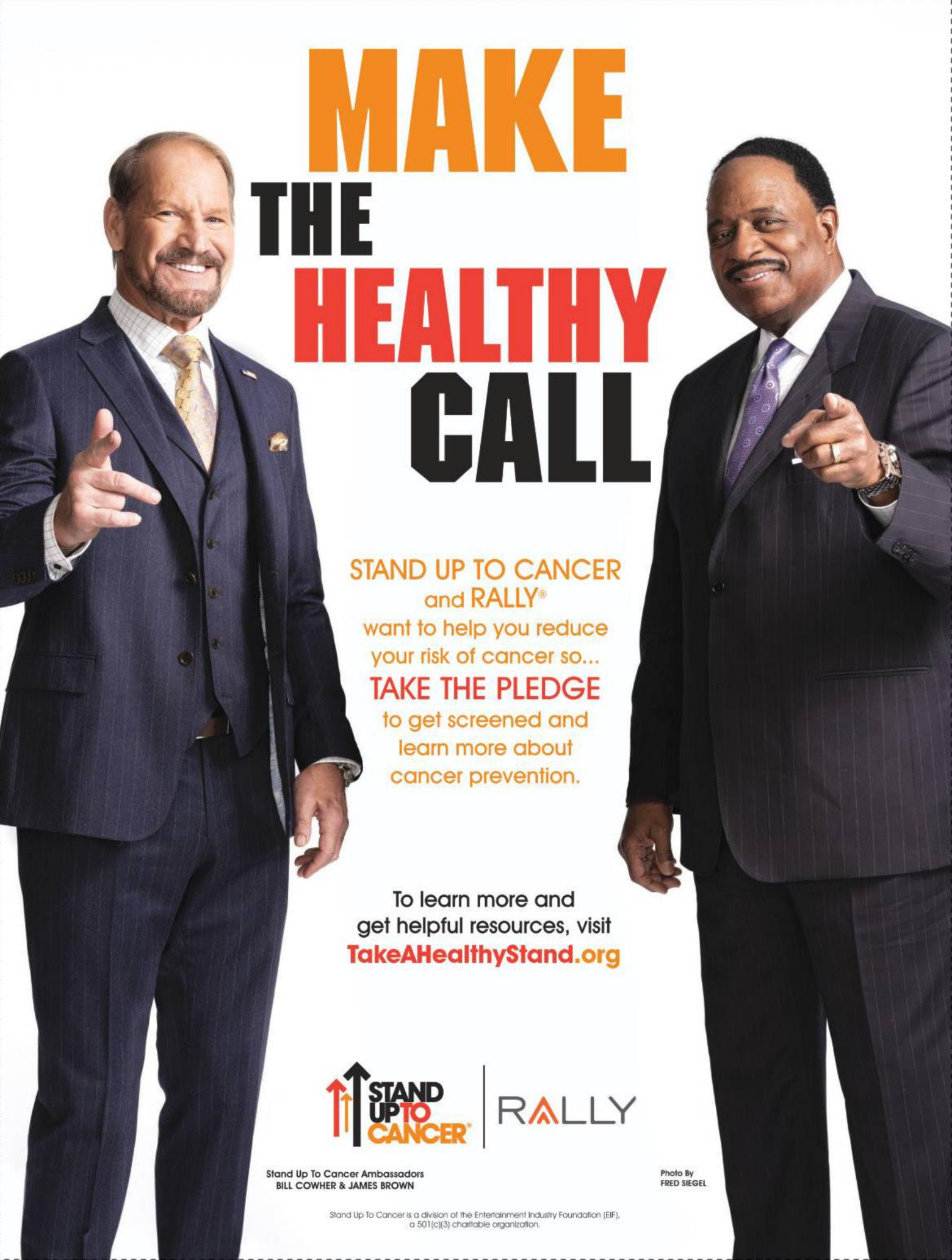
"M. l'Abbe Plessis, in an article in *Les Mondes,* says that he placed a large horned beetle, weighing some fifty grains, on a smooth plank, then added weights up to 2.2 pounds. In spite of this being 315 times the beetle's weight, the beetle managed to lift it and move it along. A human is fully a hundred times feebler in proportion. Similarly, the flea, scarcely 0.03 of an inch in height, manages to leap over a barrier 500 times its own altitude. Imagine a human jumping 3,000 feet in the air!"

Speedy Pigeons

"Carrier pigeons are being thoroughly tested, and some have shown a wonderful speed. The Ariel, a pigeon that won the $2,000 prize in the international contest in Belgium in 1871, accomplished the distance between New York and Stratford, Conn., sixty-four miles, in thirty minutes. Another bird, known as No. 6, made the journey in almost as quick a time. The carrier pigeon seems to possess a memory for places, coupled with a very strong attachment for its abode."

1973, Medicinal Plants: "*Culpeper's English Physician and Complete Herbal,* written by Nicholas Culpeper (1616–1654), listed hundreds of plants that could be 'applied to the cure of all disorders incident to mankind.' Fennel was recommended to 'break wind and provoke urine.... The ... seed, boiled in water, will stay the hiccough.' Fern roots boiled in mead killed 'worms in the body.' The foxglove was used for 'feebleness of the heart'; today it is the source of digitalis [to treat congestive heart failure]."

Scientific American, Vol. 229, No. 3, September 1973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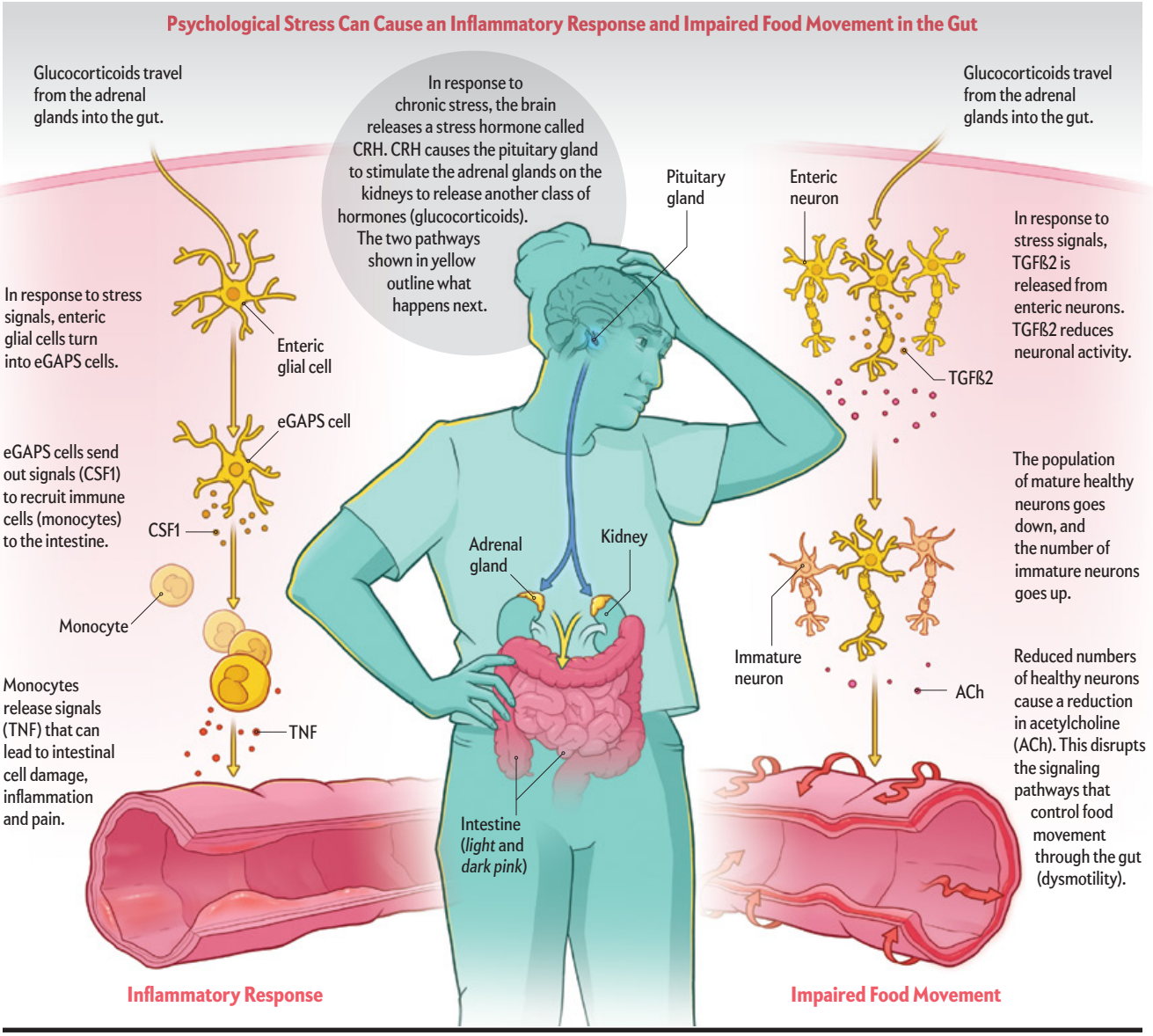
The Brain-Gut Connection

In inflammatory bowel disease, mental stress can produce two painful types of physical responses

Bouts of disabling pain, bleeding, weight loss and hospitalization that sometimes require surgery: that's the lot of about three million adults in the U.S. who suffer from inflammatory bowel disease, or IBD. (The illness has two main forms, Crohn's disease and ulcerative colitis. It is frequently associated with an overactive immune system and may have a genetic component.) Treatments often involve some variety of immunosuppressant such as a steroid drug. But even controlled cases have periodic flare-ups, and the reasons have been hard to pin down.

Now scientists have traced two detailed molecular pathways from the brain to the gut that produce IBD flares. And in three different groups of IBD patients, they found that psychological stress—a death in the family or a bad fight with a loved one, for instance—can trigger the release of brain chemicals that cause IBD symptoms. This doesn't mean IBD is all in the head, emphasizes Christoph A. Thaiss of the University of Pennsylvania, one of the researchers. But it does mean psychotherapy and targeted stress-management techniques have important—and until now underappreciated—roles to play in preventing and treating agonizing flares.



Source: "The Enteric Nervous System Relays Psychological Stress to Intestinal Inflammation," by Kai Markus Schneider et al., in *Cell*, Vol. 186; June 22, 2023 (*reference*)

O. Usykov Institute for Radiophysics and Electronics, Kharkiv

The institute has been created as a center for theoretical studies, laboratory research, and mass production design. The generation, transmission, and reception of electromagnetic waves are comprehensively studied here.Ukraine's only microwave cryogenic complex is located in the institute, which is used for research on magnetic nanoparticles.

In March-April 2022, due to the Russian invasion and the battles on the northern outskirts of Kharkiv, the buildings of the institute were damaged by shelling. The photo shows employees on the territory of the institute, who, regardless of the war, stay in the country and continue their work.

Photographer: Valentyn Kuzan

Hey. Maybe we could start fresh?

—Earth

Our world is trying to tell us something. For humans to thrive, we must rethink our values and systems to craft a framework for a healthy future relationship with our planet that isn't at odds with prosperity. Better is possible. Join us!

globalfutures.asu.edu

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Reshaping our relationship with our world