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VOLUME 323, NUMBER 5

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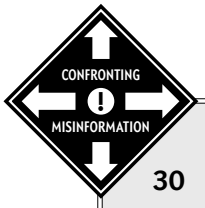


GETTY IMAGES (*Blackburnian warbler*)

ON THE COVER
Uncertainty creates conditions for misinformation to flourish—and flourish it has. As the world continues to grapple with the pandemic and the U.S. faces a high-stakes election season, how can society be less fragile to toxic media manipulation, whether it is from the highest levels of governments or homegrown?
Illustration by Hanna Barczyk.

BIG QUESTIONS FROM...
ONDREJ KRIVANEK

A pioneer in electron optics, Ondrej Krivanek discusses the fascinating possibilities now that electron microscopes can distinguish atoms, including energy-conserving computers, clean-burning hydrogen fuel, and the chance to peer inside cells to track the chemistry of life.

When Ondrej Krivanek first considered building a device to boost the resolution of electron microscopes, he asked about funding from the U.S. Department of Energy. "The response was not positive," he says, laughing. He heard through the grapevine that the administrator who held the purse strings declared that the project would be funded "over his dead body."

"People just felt it was too complicated, and that nobody would ever make it work," says Krivanek. But he tried anyway. After all, he says, "If everyone expects you to fail, you can only exceed expectations."

The correctors that Krivanek, Niklas Dellby, and other colleagues subsequently designed for the scanning transmission electron microscope did exceed expectations. They focus the microscope's electron beam, which scans back and forth across the sample like a spotlight, and makes it possible to distinguish individual atoms and to conduct chemical analysis within a sample. For his pioneering efforts, Krivanek shared The Kavli Prize in Nanoscience with the German scientists Harald Rose, Maximilian Haider, and Knut Urban, who independently developed correctors for conventional transmission electron microscopes, in which a broad stationary beam illuminates the entire sample at once.

Electron microscopes, invented in 1931, long promised unprecedented clarity, and in theory could resolve objects a hundredth the size of an atom. But in practice they rarely get close because the electromagnetic lenses they use to focus electrons deflected them in ways that distorted and blurred the resulting images.

The aberration correctors designed by both Krivanek's team and the German scientists deploy a series of electromagnetic fields, applied in multiple planes and different directions, to redirect and focus wayward electrons. "Modern correctors contain more than 100 optical elements and have software that automatically quantifies and fixes 25 different types of aberrations," says Krivanek, who co-founded a company called Nion to develop and commercialize the technology.

That level of fine-tuning allows microscopists to fix their sights on some important pursuits, such as producing smaller and more energy-efficient computers, analyzing biological samples without incinerating them, and being able to detect hydrogen, the lightest element and a potential clean-burning fuel.

Can electron microscopes help build energy-sipping computers?

We are making all kinds of fun atomic-scale devices that would minimize the energy needed for a logic operation. Computing on a much lower power budget is a frontier that people are exploring: How many gigaflops can you get per microwatt? What we're waiting for is a 10-atom transistor built out

of foreign atoms incorporated in boron nitride. I'm sure that's going to come one of these days, because you can move atoms around with the electron beam in these two-dimensional materials. Then the only problem will be trying to connect it to other transistors in the device.

Could microscopy lead to eco-friendly power sources, like hydrogen or solar cells?

Hydrogen fuel cells would be wonderful. It's one of the most abundant elements, and when you combine hydrogen with oxygen in the air, there's no pollution because what you're producing is water. If you could store hydrogen in a storage tank without having to keep it under huge pressure, you could put enough of it in your car. But to put hydrogen into the storage cell and cycle it in and out, you need to be able to see what the hydrogen is doing, where it is sitting, and to what it is bonded. That is the province of electron microscopes and their spectrometers, which tell you which elements are where. For solar cells, the issue tends to be efficiency and cost. With silicon solar cells, you get something like 20% efficiency, and you have to grow and slice and polish the silicon crystals, so it can get expensive. Can you make something cheaper and with higher efficiency? What if you could just spray a material as a thin film on a piece of plastic and get good efficiency? When you try to do that, you introduce defects called grain boundaries, because you don't have a single crystal. There was some nice work from the SuperSEM Laboratory in the U.K. showing how grain boundaries in thin-film solar cells affect their efficiency, and what you can do about it. Microscopy helps us see how we can arrange the internal structure of the material so it gives us the properties we want from an electrical point of view.

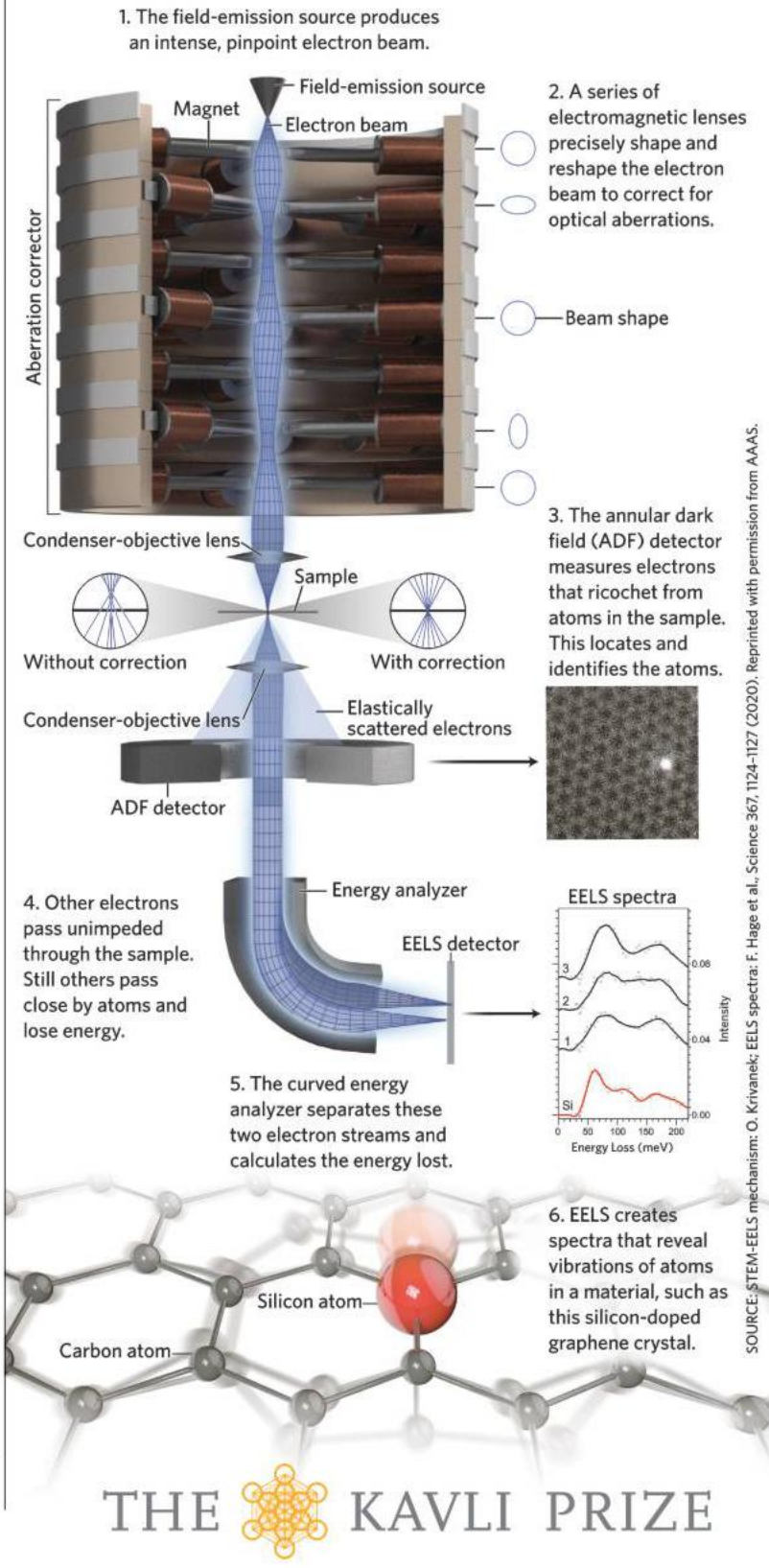
How can enhanced resolution advance the study of biological materials?

When you look at an individual cell, you want to understand what type of chemical substances sit at different places, and how they travel in the cell. How are they synthesized, and how are they metabolized into something different? I'm hoping that aberration-corrected vibrational spectroscopy will be able to answer these types of questions. Biological microscopy has typically been a race between extracting useful information from the sample and destroying it with the same beam that you're using for imaging. In vibrational spectroscopy, you don't aim the electron beam to the place you're examining; you direct it nearby. This avoids radiation damage, and allows closer examination of the samples. We can now do this in scanning transmission electron microscopes with remarkable energy and spatial resolution. I was doing a sabbatical at Humboldt University in Berlin, concentrating on precisely this, but I had to finish it prematurely because the university was shutting down due to COVID-19. Hopefully, when the world returns to normal, I'll go back to Germany, and I'll be able to say this project worked out great—or, it was a crazy idea and didn't work at all. If you know how it's going to turn out, then it's engineering. If you don't have any idea, then it's called research. And that's what we're doing right now.

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

ATOMIC VISUALIZATION

Scanning transmission electron microscopes can now resolve and identify individual atoms, thanks to electron optics advances. Adding an energy electron loss spectrometer (EELS) can even help visualize how atoms jostle and vibrate.



SOURCE: STEM-EELS mechanism: O. Krivanek; EELS spectra: F. Hage et al., Science 367, 1124-1127 (2020). Reprinted with permission from AAAS.

THE KAVLI PRIZE

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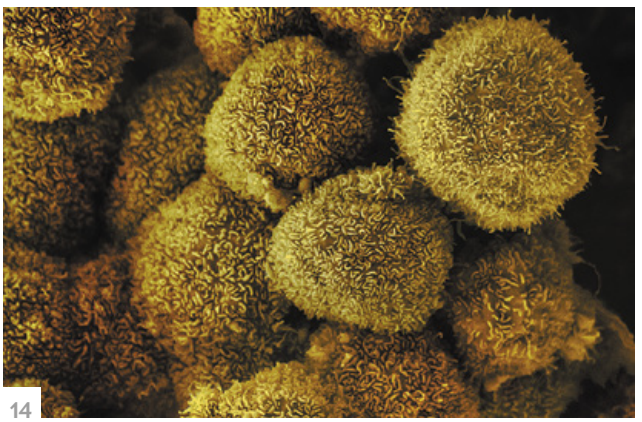
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Laura Helmuth is editor in chief of *Scientific American*.
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True Reality

This month I learned that senior editor Jen Schwartz is an evil genius at media manipulation. She produced our cover package about misinformation (starting on page 28), including a story about her own role in an Election Day drill in which she demonstrated how easily bad actors can disrupt honest news coverage. It's funny and chilling and a little too real for comfort, and I'm more grateful than ever that she is working for the side of truth and reality rather than disinformation.

Misinformation is one of the hottest areas of research right now—unfortunately because there's just so much to study. With the pandemic, election season, trolls who weaponize confusion and the massive influence of social media platforms, conspiracy theories and quackery are spreading more quickly and widely than ever. We hope that understanding the science of misinformation will help us all tell sense from nonsense and find the best ways to resist and debunk dangerous myths.

During the pandemic shutdown, lots of people are discovering the joy of watching birds. Senior editor Kate Wong was inspired by the goldfinches at her feeder to look into how birds evolved such spectacular diversity (*page 44*). As a longtime birder, I'm delighted to see this hobby becoming more popular. It's now hawk migration season, so when you're outdoors, look up, and you might see raptors heading south in a hurry.

You might not expect a story about space war to be … charming? And amusing? Satellites fighting satellites is a serious issue, and science writer Ann Finkbeiner is a serious person, but she also knows how to bring out the absurdity of a situation and get experts to tell us what they really think. Turn to page 50 and enjoy an amazing graphic within.

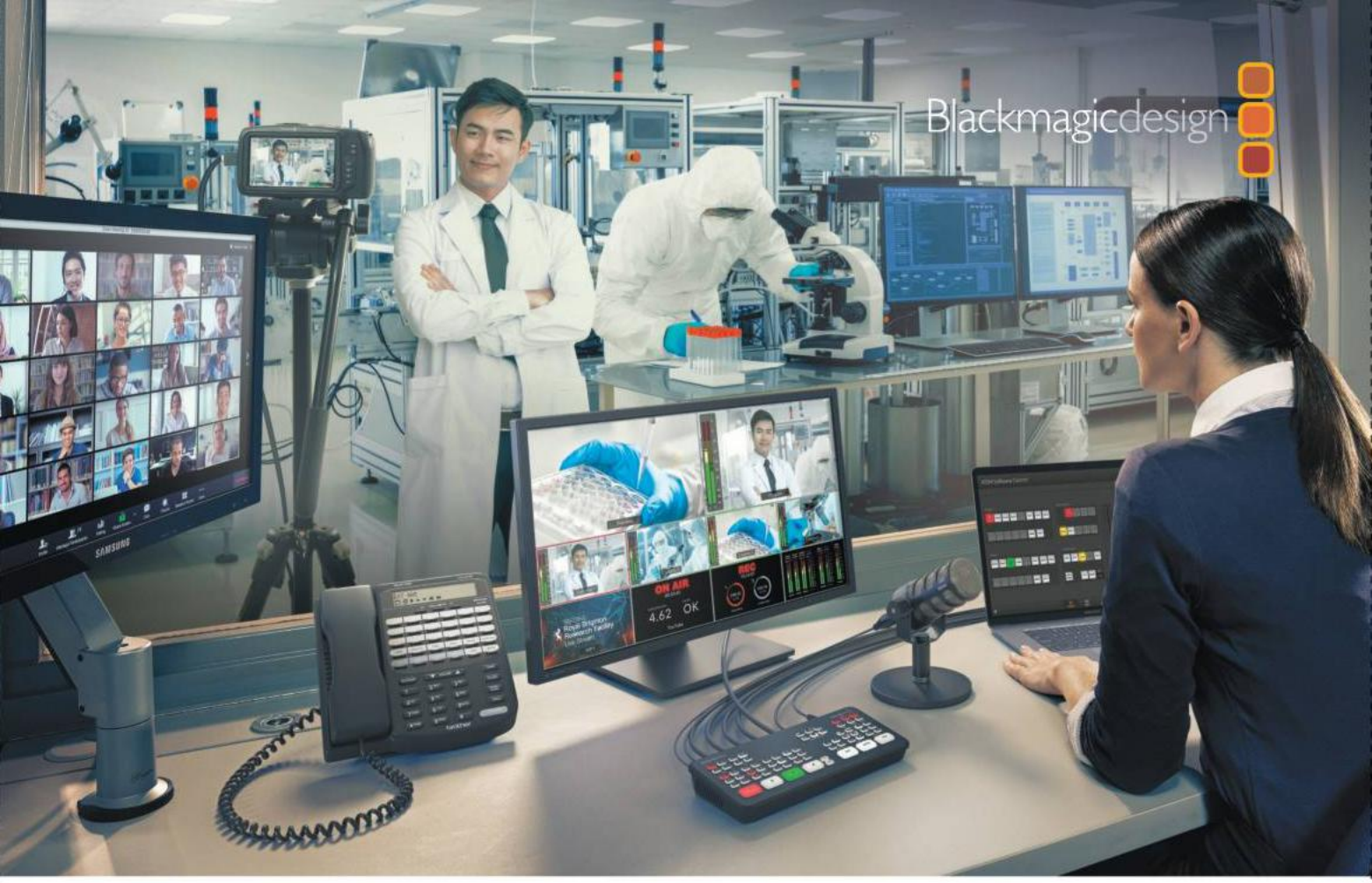
Rocket science may be challenging, but brain science is immeasurably more complicated. Beginning on page 58, journalist Diana Kwon offers a possible explanation for how psychological trauma can cause neurological symptoms in a feedback loop that scientists are just starting to piece together. The mysterious condition is called functional neurological disorder.

At a time when every conversation eventually turns to the pandemic, it's hard to imagine that we will ever forget it. But collective memory for the catastrophic influenza of 1918–1919, which killed 50 million to 100 million people, was shockingly fleeting. The story, on page 66, is by Scott Hershberger, a summer writing fellow who worked with us through a program from the American Association for the Advancement of Science.

Plenty of other plagues have shaped history, and researchers around the world are extracting pathogens' genetic material from their victims to show which diseases caused the worst mass deaths and how the germs spread around the world. The article by science writer James P. Close begins on page 70. We hope that looking at the history of past plagues can help us understand the COVID-19 pandemic, which will only be ended with science, public health measures and a shared interpretation of reality.

We got more attention than we expected for our editorial in last month's issue endorsing Joe Biden for president. More than 1,000 publications covered the endorsement, and the response was overwhelmingly positive (whew). Thanks very much to everyone who sent supportive messages, including some people who disagree with the decision but respect us for feeling a responsibility to speak up. We hope those who are disappointed in the endorsement will stick with us for everything else we have in common: a desire to understand the world, share knowledge and discoveries, and show that reality is more rich and fascinating than misinformation. SA

Illustration by Nick Higgins



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The ATEM Mini Pro model has a built in hardware streaming engine for live streaming via its ethernet connection. This means you can live stream to YouTube, Facebook and Twitch in much better quality and with perfectly smooth motion. You can even connect a hard disk or flash storage to the USB connection and record your stream for upload later!

Monitor all Video Inputs!

With so many cameras, computers and effects, things can get busy fast! The ATEM Mini Pro model features a "multiview" that lets you see all cameras, titles and program, plus streaming and recording status all on a single TV or monitor. There are even tally indicators to show when a camera is on air! Only ATEM Mini is a true professional television studio in a small compact design!

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July 2020

OBESITY AND PREJUDICE

In "Treating Patients without the Scale," Virginia Sole-Smith describes physician Louise Metz's approach to issues around weight and eating that affect individuals' health. I could not agree more with Metz, whose technique involves encouraging healthier behaviors rather than focusing on weight.

During the past 27 years of my practice of internal medicine before my retirement, I treated many hundreds of people with eating disorders whose body mass index (BMI) ranged from malnourished to morbidly obese. They taught me much about how to treat all of my patients. As the article notes, for different racial, cultural, ethnic and socioeconomic groups, there are huge disparities in societal attitudes and acceptance, as well as in treatment received from the medical community. In addition, I believe one of the greatest disparities is manifested in gender: Men are far less likely to experience bias against overweight people than women. Men also have eating disorders that are not as often recognized as they would be in women.

A. Lee Tucker, Jr. *Nashville, Tenn.*

In "The Racist Roots of Fighting Obesity," Sabrina Strings and Lindo Bacon assert that "blaming black women's health conditions on 'obesity' ignores … critically important sociohistorical factors." They also say that prescribing weight loss is ineffective and that "the most effective and ethical approaches … should aim to … [tackle] racism, sexism and weightism." That strategy provides only a partial solution to improve African-American health.

"As a Black woman and a physician, I have seen the deleterious effects of obesity."

Sylvia Gonsahn-Bollie *via e-mail*

As a Black woman and a physician, I have personally and professionally seen the deleterious effects of obesity that extend beyond subjective aesthetics. I agree that forcing individuals to conform to specific body types that are rooted in racism, classism and sexism is unhealthy and potentially harmful. But given the evidence of the increased all-cause mortality associated with obesity—especially at a BMI greater than 35—it would be a disservice not to address it in African-Americans. The work Strings and Bacon describe does not invalidate the need for obesity treatment in African-American patients with diseases related to the condition. Rather it reemphasizes that such treatment must comprehensively address nutrition, physical activity, behavior and, if needed, medication or bariatric surgery.

Additionally, for Black people globally, it is critical to incorporate the effects of personal and systemic racism, as well as other psychosocial factors, into obesity-treatment planning to truly create lasting weight loss and optimal health.

Sylvia Gonsahn-Bollie *via e-mail*

FLAVOR COMBINATION

"The Darkest Particles," by William Charles Louis and Richard G. Van de Water, describes how neutrinos emanating from the sun transition from one of the three known "flavors" to another en route to Earth. The "Neutrino Flavors" box illustrates how the cumulative contribution of a neutrino's three mass states determines its flavor during the course of its travel. The particle is shown with a sharply defined mass state combination associated with an electron neutrino at its source and one indicating a tau neutrino at its destination. But the graphic seems to suggest that between those points, the neutrino passes through a large number of mass state combinations. Do the three flavors encompass a wide enough range of combinations to account for the entire transit? If not, what is the neutrino when it is not one of them?

Allan W. Malinen
Kingsburg, Nova Scotia

I assume that there is agreement that the tau and electron neutrinos are, respectively, thought to be the most and least massive of the three known flavors. In the "Neutrino Flavors" box, an illustration of the three mass states of the normal hierarchy produces the expected result. Meanwhile the illustration of the inverted hierarchy seems to propose that the electron neutrino's predominant mass state (mass 1) is not the smallest state but the intermediate one.

Yet to maintain the expected rank order of the masses in the inverted hierarchy, the "extremely small mass" must be the electron neutrino's second most prominent mass state (mass 2). If it were mass 3, as the illustration shows, then the tau neutrino—which is dominated by that state—would easily be the least massive of the three flavors. Is the illustration in error?

Eric M. Van *via e-mail*

THE AUTHORS REPLY: To answer Malinen: If the neutrino starts out as a pure electron neutrino, then it will be in a superposition of the three known flavors as it travels from its source. Therefore, if the particle is detected downstream from that source, it will have different probabilities of being an electron, muon or tau neutrino. If the sum of these probabilities is measured to be less than one, then that result would be evidence that the neutrino's flavor is the possible fourth "sterile" type that we discuss in our article.

In reply to Van: The figures of the three mass states are correct. As they show, the electron neutrino consists of a superposition of these different states rather than having a single mass. The particle's most dominant mass state is mass 1, followed by mass 2 and then mass 3. Neutrino oscillation experiments have shown that

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mass 2 is heavier than mass 1. Yet it is not known at present whether mass 3 is heavier than mass 1 (the normal hierarchy) or lighter (the inverted hierarchy). Because the muon and tau neutrinos consist of different superpositions of these three states, it is not correct to say the tau neutrino is either heavier or lighter than the electron or muon neutrinos.

UNPROCESSED RAPE KITS

In "Justice for Rape Victims" [Science Agenda], the editors indicate that there are states and regions that are not using completed rape kits to arrest perpetrators. It would be extremely helpful if you would make a list of the local and state governments that are failing to act on the completed kits. Then your readers could contact the appropriate agency and request action.

Joe Passanise *Holiday, Fla.*

THE EDITORS REPLY: We would like to thank Passanise for his request. In fact, we have created a data visualization showing where each state stands in processing its kits, which you can see online at www.scientificamerican.com/untested-rape-kits

SEED OF DOUBT

"One Million Seed Types," by Mark Fischetti and Accurat [Graphic Science; July 2020], includes a legend that states, "Area indicates number of seeds for that genus." It seems more likely to me that it indicates the number of seed samples. Otherwise the circles would not fall into neat size units.

Simon LeVay *West Hollywood, Calif.*

THE EDITORS REPLY: The circle sizes in the graphic reflect the number of seeds per genus (as correctly labeled) rather than the number of seed samples. But LeVay brings up an excellent point that we did not address directly on the page: The circles do fall into suspiciously "neat size units." To fit them on a grid—and to make the smallest seed collections visible—the scale that informed their size was based on ranges instead of continuous values. Each circle's area was calculated according to seed numbers. But those numbers were first consolidated into discrete bins for best fit, with the aid of an algorithm.

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Earth after the Pandemic

Protecting the biosphere and eliminating injustice are part of the same fight

By the Editors

Early this year, as vast segments of the global economy shut down but before the death toll climbed, many of those privileged enough to feel relatively secure indulged a fantasy that the pandemic would paradoxically make the world more beautiful. Smog cleared from the skies, unveiling the snow-clad peaks of the Himalayas; an octopus was spotted in one of Venice's formerly murky canals; and the undersea cacophony of transoceanic shipping quieted, allowing whales to revel in one another's songs more than they had in half a century. Daily global carbon emissions fell by more than 20 percent, providing hope of real progress on climate change. It almost seemed that Earth had unleashed a virus on industrial civilization, bringing it to a grinding halt and protecting itself.

Months later, as Supercyclone Amphan devastated the northern coast of the Bay of Bengal and wildfires ravaged California, it was hard to remember that brief moment of environmental optimism. The coronavirus shock to the global economy will make barely a dent in climate change. The suffering brought by COVID-19 is catastrophic. Worldwide more than 30 million people have been infected, and one million have died. In the U.S., upward of 60 million people have become unemployed, and many are at risk of being evicted from their homes. The situation in developing countries is almost unimaginably horrific, with 265 million people teetering on the edge of starvation.

But by lifting some of the smog that had obscured the structure of modern society, the pandemic may also have shown a way forward. It is not only the exploitation of nature that undergirds modern civilization but also the exploitation of humans. Systemic inequality, injustice and racism resulting from centuries of colonialism and slavery provide the scaffolding of the global economy, which was built not only by the ingenuity and entrepreneurship of a few but also by the abuse of the many.

That idea, once bitterly contested, has now become plausible and even self-evident. Some of the least prestigious and worst-paid jobs—picking fruit, delivering parcels, bathing patients—have turned out to be the most crucial. They are also the riskiest because they involve commuting and working in conditions that increase exposure to COVID-19. In consequence, the pandemic reminds us of who performs these services. In the U.S., someone who is Native American, Hispanic or Black—whose families may have been ripped apart in the distant or recent past by global and domestic processes of wealth extraction—is roughly five times as likely to be hospitalized for the coronavirus as someone who is white.

Marginalized groups also suffer disproportionately from environmental devastation—although they do the least harm to the planet. The world's top 10 percent of income earners are responsible for up to 43 percent of the environmental impact of human society, whereas the world's bottom 10 percent contribute no more than 5 percent. Across nations, inequality correlates with worse environmental indicators—probably because the marginalized often lack the clout to fend off polluting facilities, from which the wealthy are more likely to profit. In the U.S., regions with poor air quality, where Black people disproportionately reside, also appear to have worse outcomes from COVID-19.

The pandemic has not only aggravated these stark inequities and injustices, the mass unemployment it has generated has also given millions of Americans the motivation and opportunity to express their outrage. Their impassioned protests against systemic racism may be essential to moving the U.S. to a more equitable and sustainable future. Change is in the air. City dwellers are lending a hand to neighbors who, months earlier, were strangers. And local food movements are providing hope of reducing dependence on highly polluting and often exploitative global supply chains.

Climate activists have long argued that saving Earth and fighting for justice and equality are one and the same. That conviction undergirds the Green New Deal, a package of social, environmental and economic reforms advocated by progressive U.S. politicians. Ensuring that this vision and its international counterpart, the Global Green New Deal, are transformed into reality will require sustained pressure from social movements. Even before the pandemic, the struggles of Indigenous peoples, such as that of the Standing Rock Sioux to defend their right to clean water, and schoolchildren's strikes to force action on climate change were inspiring millions around the globe. "Another world is not only possible, she's on her way," prophesized novelist Arundhati Roy. "On a quiet day, if I listen very carefully, I can hear her breathing." SA

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Illustration by Brian Stauffer

Victoria Herrmann is managing director of the Arctic Institute and an assistant research professor at Georgetown University.

Preparing for the Wrong Arctic Crisis

A newly named diplomat has no experience with climate issues

By Victoria Herrmann

In late July the Trump administration appointed James DeHart as the State Department's first U.S. coordinator for the Arctic. A member of the Senior Foreign Service, DeHart has spent much of his 28-year career working to resolve conflict. He led the U.S. Provincial Reconstruction Team in Afghanistan, directed the State Department's Office of Afghanistan Affairs and, most recently, was the top U.S. negotiator in defense cost-sharing talks with South Korea.

While DeHart's post as deputy chief of mission in Oslo provides him with three years of Arctic experience, his primary expertise lies in armed competition and diplomacy. There is just one problem: in the Arctic, cooperation consistently prevails over conflict, and where transnational governance is based on dialogue, mutual interest and respect for Indigenous rights. The United Nations Law of the Sea dictates who owns what, and the Arctic Council, a high-level intergovernmental group that addresses issues faced by Arctic nation-states and Indigenous peoples, remains an active forum for cooperation, coordination and interaction. Even as tensions simmer in Russia, the West and China, the North continues to be a place where risk of militarized conflict is minimal. Disputes about investment in northern infrastructure, navigation rights along sea routes, and fisheries management and total allowable catches all derive from increasing economic competition.

Yet the truly catastrophic threat is climate change. The northern polar region is warming at more than twice the rate of the rest of the world. This past July sea ice in the Arctic hit an all-time low. In June heat waves rippled across the area, with the Siberian Arctic town of Verkhoyansk recording an all-time high for the Arctic Circle of 100.4 degrees Fahrenheit. And Arctic wildfires now rage so fiercely that they have burned from one summer through the winter and into the next summer without dying.

Climate change in the North is an everyday, life-threatening reality. The four million people who call the Arctic home live in a continual state of emergency, facing threats to their families' health, to their food security, and to local economies that support global fishing, mining and shipping industries. DeHart's impressive record of negotiating status of force and defense cooperation is critical for leadership in conflict-torn regions such as central Asia. It does not prepare him to coordinate U.S. policy in a region where climate change is the number-one threat.

The U.S. has been described as a reluctant Arctic nation because of its history of a vacuum of leadership, inadequate investment and no strategic vision for the region's future. But it cannot afford to maintain its ambivalence toward the Arctic in a rapidly warming world. We need a whole-of-government approach to tackle today's economic, emergency-response and human security challenges. I argued as much in testimony before the House Committee on Homeland Security in September 2019.

Most of all we need leadership driven by regional expertise, experience and respect—someone who not only understands problems such as thawing permafrost and sea-ice melt but who also can lead regional cooperation. Such seasoned leaders already exist among the many well-qualified Alaska Native diplomats who serve in Indigenous people's organizations with Permanent Participant status at the Arctic Council. These leaders represent U.S. citizens in Arctic Council negotiations, understand the gravity of climate impacts and make informed policy decisions based on the nuanced, localized knowledge that comes from living in the Arctic.

Past and current U.S. chairs of organizations such as the Inuit Circumpolar Council, Gwich'in Council International and the Aleut International Association offer a robust pool of capable candidates. These individuals can build a more inclusive dialogue on diplomacy, policy and government investment in and for the Arctic, and they could ensure that decisions made in Washington assess the climate impacts that are already costing billions of dollars in damage, devastating livelihoods and causing irreplaceable cultural loss.

By choosing DeHart to lead U.S. Arctic policy, we are preparing for the wrong threat. It is a mistake we cannot afford to make. SA

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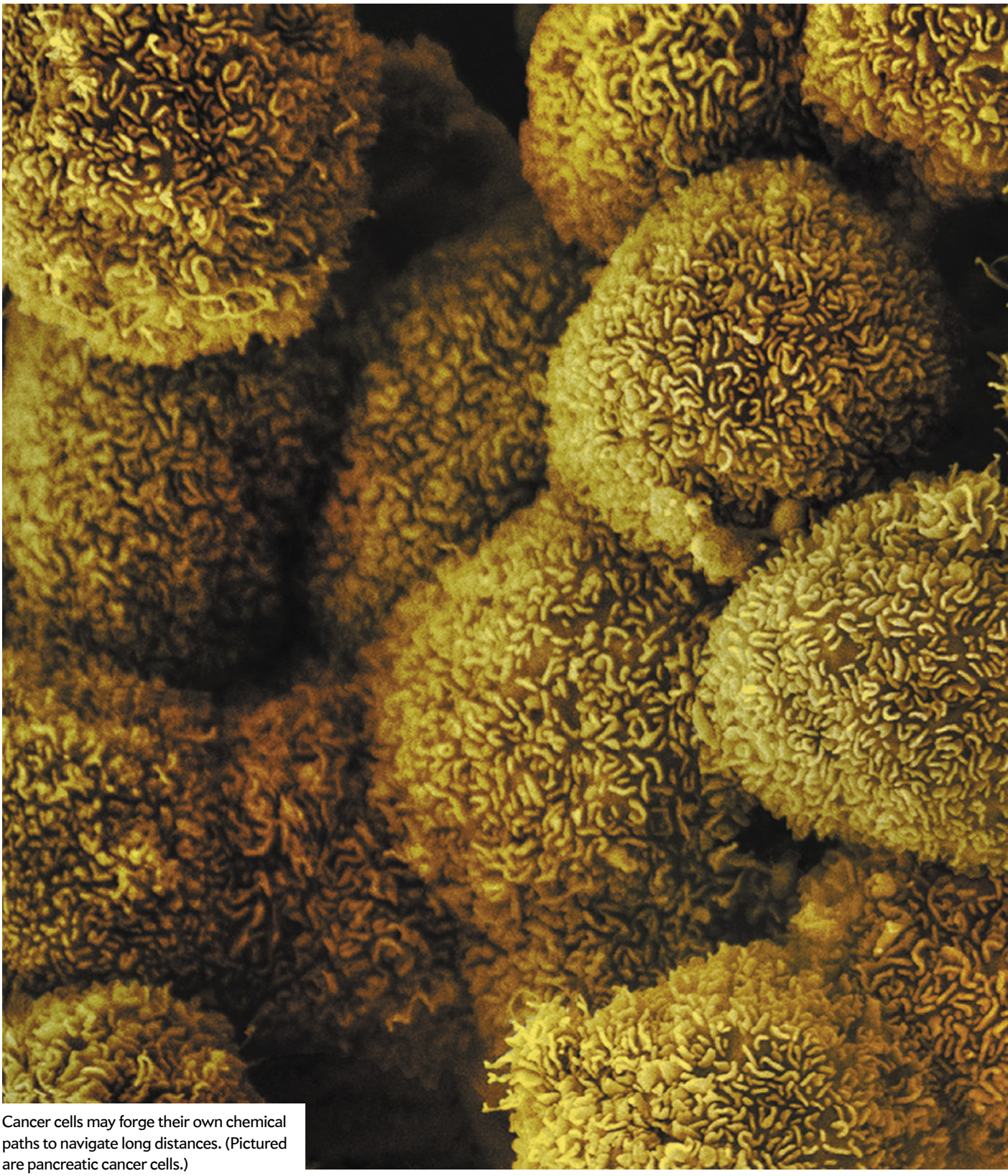
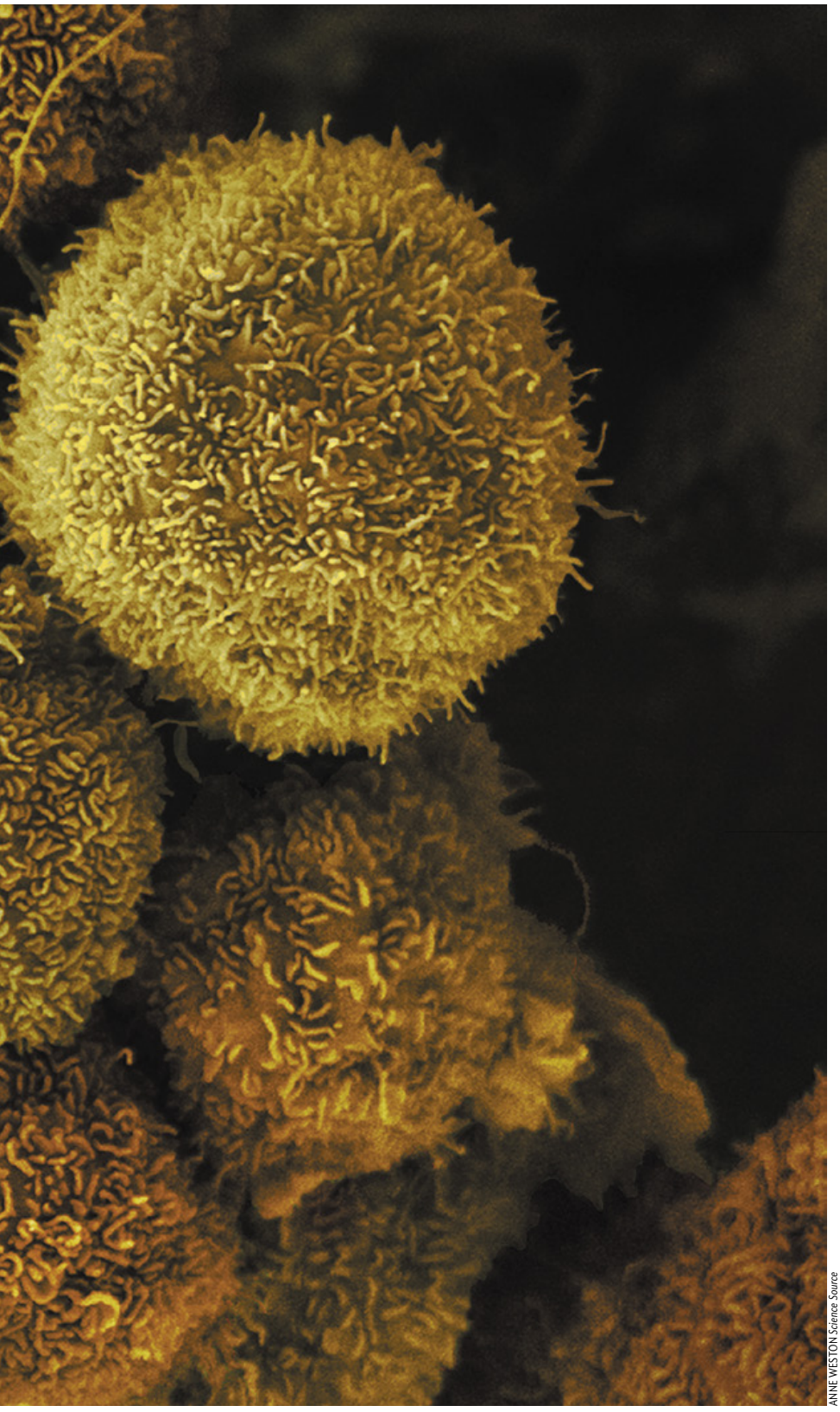
Illustration by Thomas Fuchs

ADVANCES



Cancer cells may forge their own chemical paths to navigate long distances. (Pictured are pancreatic cancer cells.)



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INSIDE

BIOLOGY

Cells in a Maze

A Pac-Man-like strategy guides both amoebas and cancer cells on complex paths

Cells can make incredible journeys—sometimes even traversing the entire body. They navigate by chemotaxis: moving based on changing concentrations of particular chemicals that point the way to the target area. But this kind of gradient cannot extend for long distances without trailing off, so scientists have wondered what guides cells over the chemical hills and valleys of a longer trip. Understanding the process could someday help researchers better predict how cancer will spread throughout the body or explain how cells get to the right places in a developing embryo.

Now, in a study published in *Science*, researchers have used miniature mazes to illustrate how two kinds of organisms—one a dirt-dwelling amoeba and the other a mouse cancer cell line—manage these seemingly impossible journeys. Rather than traveling along a preexisting gradient the entire way, the cells create one themselves: they break down the chemical they are tracking as they encounter it, so that there is a higher amount ahead of them and a lower amount behind. Like gathering string while moving through a labyrinth or Pac-Man following a trail of dots, the chemically depleted path the cells leave behind keeps them binding to—and following—the guide in front of them.

Researchers already knew that certain cells can generate their own gradients as they move, but they did not know how

effective this strategy could be for long treks through a body. The new study shows that both a mammalian cancer cell line and an amoeba can use this process to travel through a maze, suggesting it may be a key tactic for cells that navigate long distances.

Luke Tweedy, a researcher at the Beatson Institute for Cancer Research in Glasgow, and his colleagues reasoned that following a winding path through the intricate topography of an organism might be a lot like traversing an actual maze. To examine this cellular pathfinding, they chose to focus on the amoeba *Dictyostelium discoideum*, or "*Dicty*" for short, and mouse pancreatic cancer cells. *Dicty* cells are known for their long-range navigation using chemical gradients—they can be "chemotactic prodigies," as Tweedy puts it.

Dicty lived up to its reputation, needing only an hour to solve a complex maze laced with chemoattractant that took the cancer cells several days. But both types ultimately made it through. The researchers tested the cells in several mazes, some with shorter or longer dead-end branches and different forks. When cells faced a choice between a dead end and a true path, a few wayward ones would dispatch all the chemoattractant trapped in the cul-de-sac. The rest then oriented to the other fork, which was still flowing with the alluring molecules.

The use of this tactic by both cell types hints at a commonality among cells engaged in long-distance orienteering. The outcome "is really interesting and demonstrates that self-generated gradients are a universal mechanism for steering directional migration of groups of cells for long distances," says Pablo Sáez, a biochemist at the University Medical Center Hamburg-Eppendorf in Germany, who was not involved in the new study. He adds that the result highlights the usefulness of some of the techniques involved, such as using mathematical modeling to predict how the cells might behave and testing those predictions in mazes.

One memorable test was modeled on the famous human-scale maze of hedges at Hampton Court Palace near London. They chose it, Tweedy says, for "razzle-dazzle" and to "capture the imagination." *Dicty,* the prodigy protist, not only solved this maze but also managed to use its self-generating gradient skills to find a shortcut.

"I think the design of the mazes is really clever," says Denise Montell, a molecular and cellular biologist at the University of California, Santa Barbara. "They are a really good device for probing how cells make decisions—although I don't think cells really encounter mazes in real life." She suggests that cells might also use other mechanisms to travel long distances: for instance, a moving source might drop chemical signals that they can follow.

The team's research methods and experimental design could be tailored to investigate the behavior of other migrating cells in the human body, too—such as immune cell activity or the pathological journeys of metastatic cancer cells, Tweedy says: "They use the same fundamental mechanism of migration, [in which] receptors detect attractants and guide the cytoskeleton to move the cell."

In fact, the similarities are strong enough that Tweedy sees many ways to use knowledge of amoeba pathfinding to better understand human cell behavior. For instance, maze-solving ideas could help predict glioblastoma cancer's paths through the brain.

Montell says the findings could also be

ANIMAL BEHAVIOR

Bat Signal

Echolocators need more food in noisy environments

Bats have to leave the safety of their roosts every night to find food. That takes energy: their insect prey must provide them with enough fuel to offset the cost of hunting in the first place.

Because bats use the same chest and abdominal muscles for both flying and producing echolocation calls, many researchers thought vocalizing while airborne would not consume significantly more energy than flying alone. But a new study has thrown that idea into serious doubt. The results were published in *Nature Ecology & Evolution*.

"When they are calling quietly … those original assumptions hold," says Shannon Currie of the Leibniz Institute for Zoo and Wildlife Research in Germany. But "getting loud becomes extremely expensive."

Nathusius's pipistrelle bat

ALAMY

Currie and her team measured metabolism and echolocation intensity for nine Nathusius's pipistrelle bats, captured from urban areas in Berlin and released after laboratory tests. When subjected to just the normal ambient sounds while flying in a wind tunnel, the bats called at 113 decibels. But when the researchers played extra ultrasonic noise, the bats "shouted" at 128 decibels—requiring about 30 times as much energy, Currie says. Although their calls are inaudible to humans, this jump in volume is proportionally equivalent to the difference between a nearby

relevant for understanding the behavior of especially peripatetic cells found in embryos. Some, called melanocytes, disperse throughout the embryo and give skin its pigment by producing melanin. Later in life they can also be the source of melanoma, and they can exhibit similarly proficient wayfinding behavior in metastasizing. That cells might achieve both outcomes through self-generated gradients "is a really interesting concept that's nonobvious and probably important," Montell says.

The study results could also offer a rare window into other early processes in mammalian embryos. One example is the cells that eventually set up shop in the gonads, after starting far away from their target early in an embryo's development. These so-called germ cells have to find their way over embryonic hill and dale to get to the appropriate destination.

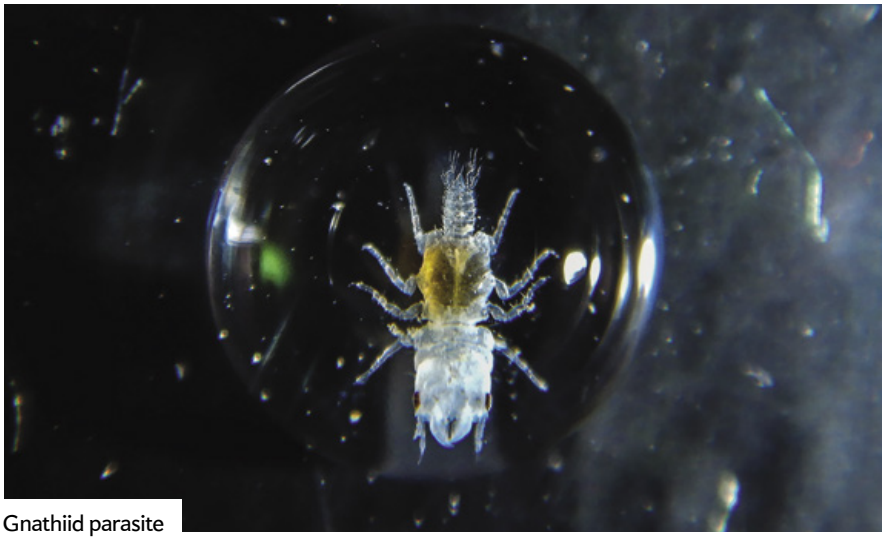
If the behavior of *Dicty* and the much slower pancreatic cancer cells is indeed universal, then germ cells may use a similar tactic to find the future gonads and avoid taking a wrong turn toward, say, the gut. Perhaps, when building complex organisms, sometimes cells can get where they are going only by forging their own path. —*Emily Willingham*

chainsaw and a jet engine, says University of Winnipeg biologist Craig Willis, who specializes in bats and was not involved in the new study.

To compensate for the additional calories they burn by turning up their volume so dramatically, the bats would have to gobble up an extra half a gram of insects (around 7 percent of their body mass) each night. "That's a turkey dinner for us; that's a big deal," Willis says.

Getting enough nourishment to afford calling over the sounds of human-generated ultrasonic noise, from traffic or heavy machinery, for example, may be difficult for bats in habitats with dwindling insect populations. "In many ways, insect conservation is bat conservation," Willis says, "and we're in the midst of this insect apocalypse where we're losing insects at alarming rates." What that means, Currie says, is that bats in many areas now have to work harder to find the fewer insects available. If they burn more calories hunting than they acquire from their prey, it could spell trouble for the flying mammals. Human-made noise adds yet one more hurdle to their survival.

—*Jason G. Goldman*



Gnathiid parasite

GENETICS

Surfing Parasites

Major hurricanes scramble marine creature populations

Just after researchers wrapped up fieldwork for the season in the turquoise waters between the Virgin Islands and Puerto Rico in 2017, back-to-back major hurricanes tore through their study sites and laboratories. It was a serious setback in the team's work with little-known parasites called gnathiids, whose young latch onto saltwater fish and feed on their blood.

But the misfortune also presented a rare opportunity to study how catastrophic hurricanes impact marine animal populations, says molecular ecologist Juan Andrés Pagán, a graduate student at the University of Porto in Portugal and lead author on a recent study in *Scientific Reports*. Every year since 2013, the team—which calls itself Gnathiid Gnation—had collected a species it named for Bob Marley (*Gnathia marleyi*), found in coral reefs. After the hurricanes the researchers returned to collect more specimens. They braved jellyfish and sharks to set traps for the gnathiids, which are most active at night.

For their new study, the scientists sequenced gnathiid DNA from population samples collected at the various sites before and after the hurricanes, which were the most intense consecutive storms to hit the area in decades. "We were able to pretty clearly establish that, prior to the hurricanes, these populations were stable," Pagán says, meaning the parasites remained in the same isolated areas year after year.

After the storms, things changed.

Gnathiids are bad long-distance swimmers. Under normal conditions they stick to small areas, similar to other invertebrates such as crustaceans and mollusks. But *G. marleyi* rode the 2017 hurricanes over unusually long distances, with some apparently traveling more than 250 kilometers. The researchers found that this displacement led to a "mixing of the pool" and, in turn, a more genetically similar gnathiid population, says team leader Paul Sikkel, an Arkansas State University marine ecologist and study co-author. "The hurricanes homogenized all that," Sikkel says. "At any one site the diversity became higher. But overall [the populations] became more even because things were being moved around." This may be the first clear, genetics-based evidence that hurricanes affect the genetic diversity of a marine species, he says.

"The kicker here for me is climate change," says Richard Aronson, a marine biologist at the Florida Institute of Technology, who was not involved in the study. If hurricanes increase in intensity as predicted, Aronson says, the study suggests there may be more genetic homogenization among some marine animals that would otherwise remain in isolated populations. This would make peripheral populations less likely to cleave off and create new species, he adds.

The researchers are also investigating whether the parasites spread blood-borne pathogens that could harm fish populations. If that is the case, Sikkel says, this study may illustrate the potential for parasite-borne disease outbreaks in the wake of future major hurricanes. —*Stephenie Livingston*

MATTHEW NICHOLSON

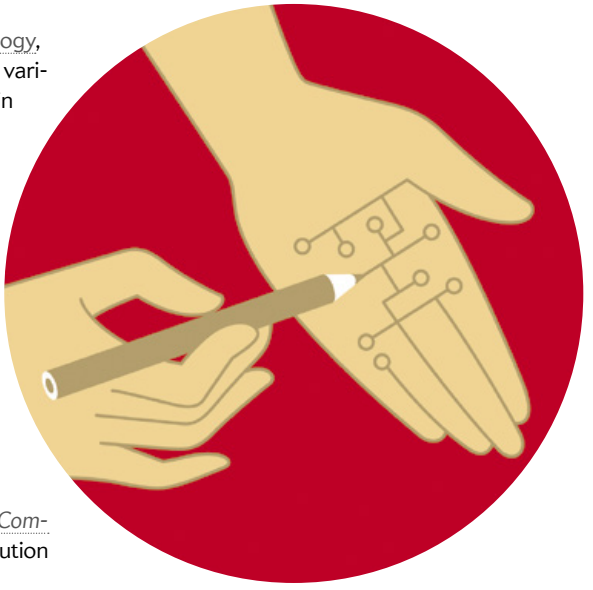
MEDICINE

Sketchable Sensor

A pen-and-ink method can produce cheap wearable health devices

A handful of stencils and three pens sound like materials for a child's art project. But researchers have now used these tools to draw functional health monitors directly on human skin.

Wearable sensor technology, which helps doctors check a variety of health indicators, has in recent years advanced from bulky devices to flexible patches that stick to people like temporary tattoos. These prefabricated sensors can be expensive, however. They also tend to follow skin contours imperfectly, making them sensitive to the wearer's motion. Researchers say that a new drawn-on-skin electronics system, described in *Nature Communications*, could offer a solution to both problems.



A team led by biomedical engineer Faheem Ershad of the University of Houston first developed a conductive ink using silver flakes in a polymer solution that is safe to use on human skin. The researchers loaded the ink into modified ballpoint pens, then placed a stencil made of tape and film on a volunteer and traced within it to draw the requisite circuitry. "It's like a kindergartener learning how to draw shapes," Ershad says. "It's really that simple." Within five minutes the ink dried to create a working sensor. The researchers then taped on a standard electrical lead to provide power and transmit data to a computer.

Using just this type of ink, the team measured skin hydration and the electrical activity of heart and skeletal muscles. Because the sensor conformed perfectly to the skin, wearers could walk around without jarring it and thereby reducing data quality. The ink resisted sweat and rubbing but was easily removed with a wet paper towel and soap. "It's robust and very easily applied on any body part," says Dmitry Kireev, who researches wearable bioelectronics at the University of Texas at Austin and was not involved in the study. "It's a very elegant solution."

For more complex devices, Ershad's team used two additional inks: one served as a semiconductor, and the other acted as a dielectric (a type of insulator). Drawing different layers with each ink, the researchers crafted temperature and strain sensors on a sheet of skinlike silicone. "The authors already demonstrated many very attractive applications," says Zheng Yan, a biomedical engineer at the University of Missouri, who was not involved in the new research. Yan and his colleagues have developed similar technology using pencils and paper, but their method is limited to passive conductors that cannot introduce energy into a circuit. By drawing active electronics such as transistors, which can function as switches or amplifiers, Ershad says that he hopes to create sophisticated sensors to detect health indicators ranging from compounds in sweat to the brain's electrical activity.

The researchers plan to eventually make their sensors truly wireless by incorporating more advanced ink-based circuits. After that achievement, they say, people could use affordable kits of stencils and pens to monitor their own health at home. —*Scott Hershberger*

Illustrations by Thomas Fuchs

CLIMATE CHANGE

Gas Houses

Nationwide analysis shows neighborhoods' energy use

If U.S. home energy consumption were a country, it would rank as the world's sixth-largest greenhouse gas emitter. To bring housing emissions in line with international goals to limit global warming, planners must sift through variables such as local climate, building age and size, and occupant income.

A recent study in the *Proceedings of the National Academy of Sciences USA* provides a new nationwide analysis evaluating these factors. The researchers fed detailed building data from 93 million homes (gleaned from a database of U.S. tax assessor records) into computer models that accounted for local fuel sources to estimate home emissions.

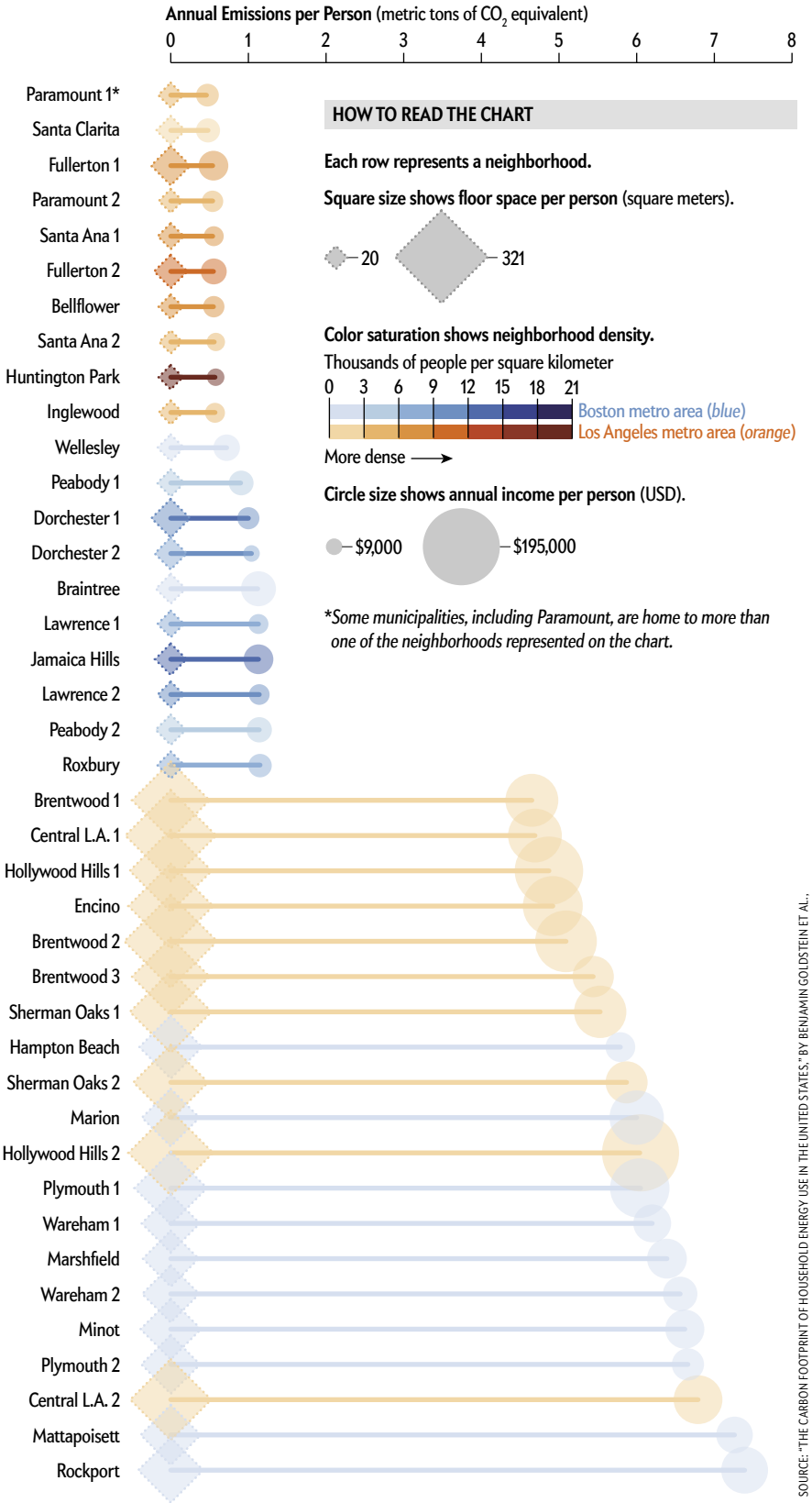
One clear result was that wealthier people's homes in America tended to be larger and produce about 25 percent more emissions than those of low-income people. This relation held when the researchers dug down to compare neighborhoods within very different cities such as Los Angeles and Boston; in L.A., for instance, some affluent neighborhoods had emissions 15 times higher than nearby low-income areas.

Study co-author Benjamin Goldstein, a researcher at the University of Michigan, was surprised by another finding: dense apartment complexes are not essential to meet emissions goals. The data suggest single-family housing on small lots in certain areas, such as some in Los Angeles, could also reach international targets as carbon-free energy sources become more common. "Not everything needs to look like Brooklyn or Manhattan to be low energy," he says.

Anu Ramaswami, a Princeton University environmental engineer, who was not involved with the study, cautions that its emissions-estimating models may not capture efficiency measures taken by some homeowners. But she says the research could set an example for municipality-level analyses. For example, such studies could help officials determine how to tailor specific local building policies to best reduce emissions, such as by encouraging smaller lot sizes or alternatives to heating oil.

—Andrea Thompson

Neighborhoods with the Highest and Lowest Greenhouse Gas Emissions in the Boston and Los Angeles Metro Areas



SOURCE: "THE CARBON FOOTPRINT OF HOUSEHOLD ENERGY USE IN THE UNITED STATES," BY BENJAMIN GOLDSTEIN ET AL., IN *PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES USA*, VOL. 117, NO. 32; AUGUST 11, 2020

Graphic by Amanda Montañez

Adult male elephant seals fighting

ANIMAL COGNITION

Brawn Song

Male elephant seals perfect unique competitive calls as they age

In the ferocious arena of a northern elephant seal colony, where few males ever get to mate, jostling suitors often face bloody battles over access to groups of females. And these boisterous bulls have a dramatic way of making their presence known to rivals: individuals identify themselves via rhythmic, guttural calls, accompanied by body slams that literally shake the ground around them.

Now research indicates that the seals are not born with these identifying signals. Rather they develop their unique brands of vocal bravado as they age, according to a recent paper published in *Animal Behaviour*.

The researchers recorded more than 440 calls from 47 male elephant seals at various stages of development in California's Año Nuevo State Park. In this colony of 2,000 animals, a dominant male may vie with 50 top competitors—each of whom possesses his own call. These vocalizations develop around the same time as the seals carve out jealously guarded territories of about 20 square meters.

Less established younger males, in contrast, are "acoustically inconspicuous" and produce short, unstructured calls. They seem to avoid standing out, which may help them gain time to mature, says lead author Caroline Casey, a graduate student in ecology and evolutionary biology at the University of California, Santa Cruz. At around the age of eight or nine, the seals finally settle on a personal song.

"It's really when they have a shot at reproducing and becoming socially competitive that these signature calls start to emerge," Casey says.

The resulting recognition comes in handy, as male seals appear to listen for—and avoid—individuals who have previously bested them in fights. Instead they target their competitive energies toward bulls with whom they know they are more evenly matched.

Casey suspects that the ruthless nature of male elephant seal society is what prompts the development of individualistic vocalizations. To explore that difficult-to-prove connection, she says, she would like to also analyze seal calls from less tightly packed communities, which could be less competitive.

Luke Rendell, a biologist in the Sea Mammal Research Unit at the University of St Andrews in Scotland, who was not involved in the study, agrees that this motivation is a possibility. Rival seals' ability to acoustically differentiate themselves from one another may even be something they learn from their elders around the point of reaching sexual maturity, he suggests.

"My hunch is that there is some learning involved," Rendell says. He praises the study for including enough data from seals in different age groups to clearly show the transition from indistinct to distinct calls: "I thought it was a really significant contribution." —*Chris Baraniuk*

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IN THE NEWS

Quick Hits

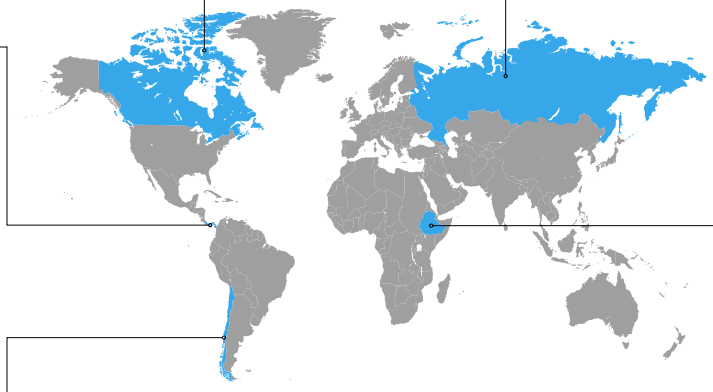
By Scott Hershberger

CANADA

The last fully intact ice shelf in Canada collapsed into the Arctic Ocean this summer. Located in the territory of Nunavut, the Milne Ice Shelf lost 80 square kilometers of ice—40 percent of its area—in just two days.

RUSSIA

An analysis of ancient woolly rhino DNA from Siberia revealed that the population size was stable for thousands of years before the mammal's extinction 14,000 years ago, suggesting that a warming climate—not hunting by humans—most likely triggered its demise.



PANAMA

Vampire bats monitored at the Smithsonian Tropical Research Institute have fewer interactions with family and friends when ill, biologists say. But they do not seem to stay apart intentionally—instead sick bats are simply too lethargic to call out to or groom one another.

ETHIOPIA

Paleoanthropologists unearthed a 1.4-million-year-old hand ax made from a hippo's leg bone. Together with recently discovered stone tools, the ax indicates that *Homo erectus* had a diverse tool kit several hundred thousand years earlier than scientists had suspected.

CHILE

Living 6,700 meters above sea level, a yellow-rumped leaf-eared mouse found at the summit of the dormant volcano Llullaillaco is the highest-dwelling mammal ever documented. It remains unclear how the animal survives the oxygen scarcity and freezing temperatures at this elevation.

ANTARCTICA

Contrary to researchers' expectations, methane-eating microbes failed to rapidly contain the first methane leak detected on the Antarctic seafloor. The finding means more of the potent greenhouse gas may have been pouring into the atmosphere than previously thought.

For more details, visit www.ScientificAmerican.com/nov2020/advances

ENGINEERING

African Skies

Space weather sensors will monitor solar emissions that threaten GPS and radio signals

A new network of dedicated antennas in Africa will lend insight into the havoc that storms of charged particles from the sun wreak on satellite and radio communications. Zambia set up its first such sensor in March—one of eight multifrequency receivers being deployed around the continent, in addition to four already operating in South Africa. Kenya and Nigeria will install their receivers by the end of the year.

Feeding into an upgraded space weather center scheduled to open in South Africa in 2022, the network will provide real-time data on how solar storms distort the ionosphere, the charged outer layer of Earth's atmosphere. This distortion can have dangerous consequences, says Mpho Tshisaphungo, a space weather researcher at the South African National Space Agency (SANSA). Signals between crucial satellites and the ground pass through this region, where charged particles can cause interference. Also, high-frequency radio signals (often used in defense and emergency services communications) have to bounce off the ionosphere; Tshisaphungo notes that when solar storms alter the layer, "the radio signal may either be attenuated, delayed or absorbed by the ionosphere."

South Africa has already been providing global networks with information about the ionosphere above the country in periodic batches, relying on satellite and ground data from international space weather programs. The new network will give Africa its first access to 24/7 local details on how the sun's behavior is affecting the atmosphere overhead, researchers say.

"While there are international data available, if you want to look at what's happening on the African continent, then you need to take measurements in Africa," says John Bosco Habarulema, a space scientist at SANSA. Habarulema, researcher Daniel Okoh of Nigeria's National Space Research and Development Agency, and their colleagues developed a model last year that maps electron density in the ionosphere and fills in measurement gaps. (Tshisaphungo is also a co-author.) The new local receivers will boost this model's accuracy and let it describe fluctuations over the full continent.

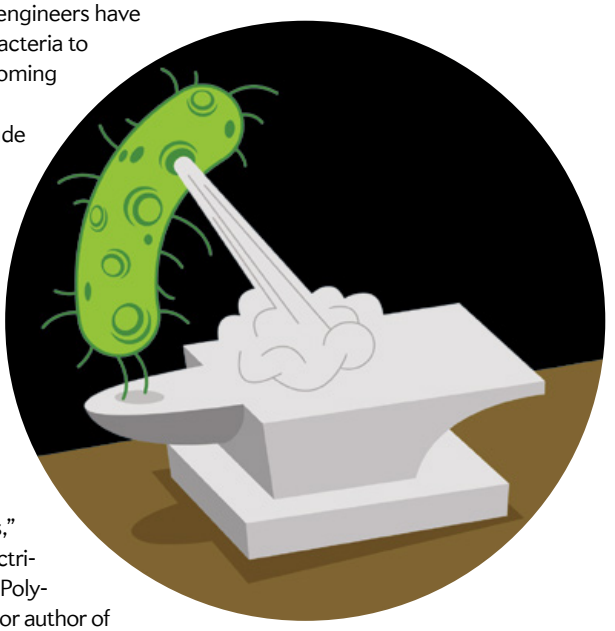
"We need to have the global perspective and put that [data] into our global models," says Terry Onsager, a physicist at the U.S. National Oceanic and Atmospheric Administration's Space Weather Prediction Center. "But at the same time, space weather disturbances can vary enormously from location to location." And it is becoming increasingly important to model the ionosphere's behavior, he says, because "we're getting more and more reliant on technologies that are reliant on space weather." —*Sarah Wild*

BIOENGINEERING

Breathing Metal

Anaerobic bacteria synthesize a promising "2-D" material

Scientists have known for more than a century that some bacteria can breathe anaerobically, or without oxygen, but only in recent decades have researchers started exploiting this property to fabricate useful materials. Now electrical engineers have found a way to use such bacteria to manufacture an up-and-coming two-dimensional material called molybdenum disulfide (MoS_2), which can form a sheet just a few atoms thick and holds promise for future electronics. The new finding, published in *Biointerphases*, could help avoid a daunting synthesis process that requires a harsh environment.



"Graphene is the breakout superstar of the two-dimensional materials," says Shayla Sawyer, an electrical engineer at Rensselaer Polytechnic Institute and a senior author of the paper. But MoS_2 is "different in that it brings a new 'skill.'" Graphene and MoS_2 are both strong and flexible, and they are useful for building futuristic sensors and energy-harvesting systems. Graphene is an electrical conductor, however, whereas MoS_2 is a semiconductor—a substance whose conductivity can be manipulated by outside stimulation, such as light.

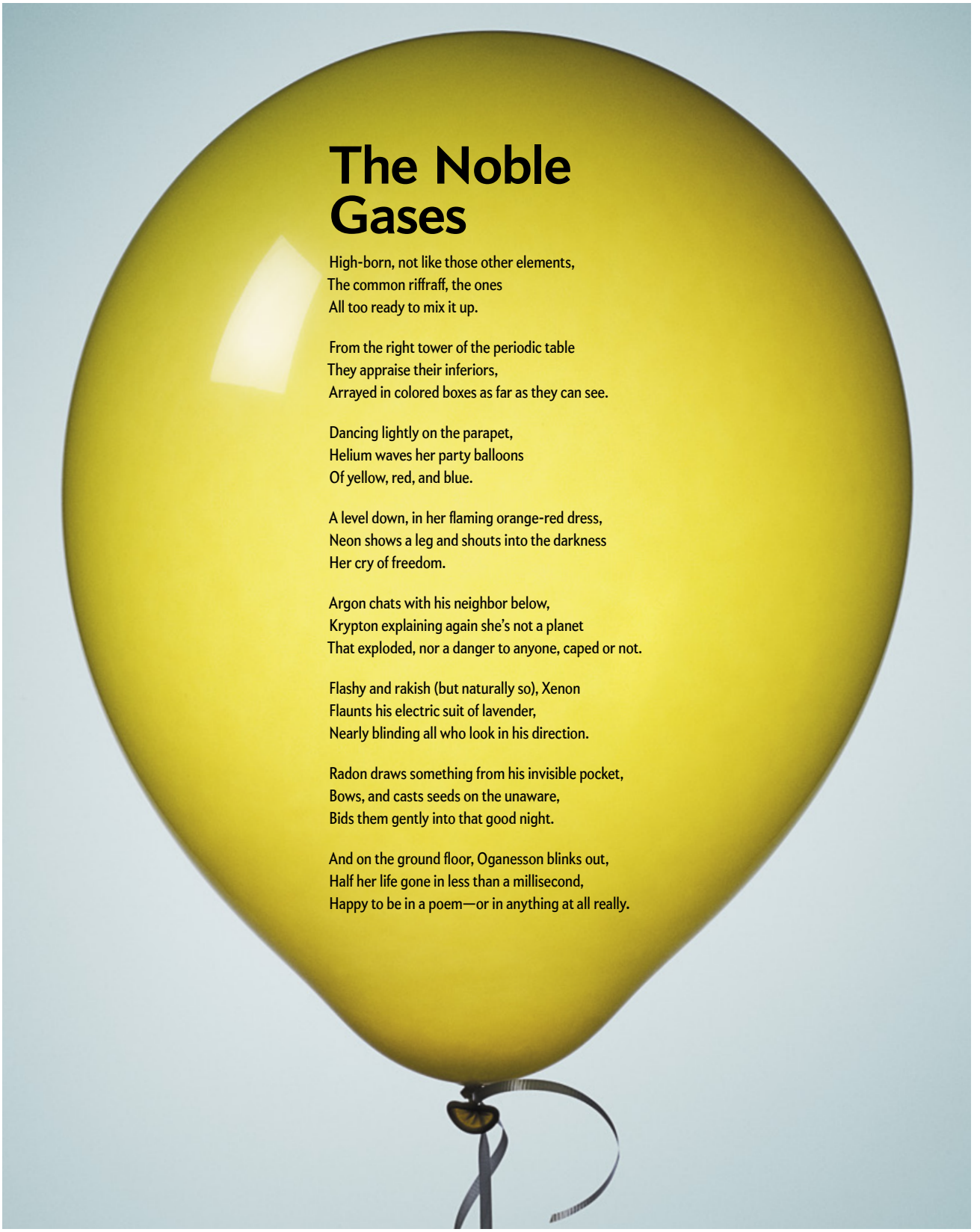
MoS_2 is "also a little bit more chemically versatile," Sawyer says. The compound's surface can easily be altered to help capture microbes, for example. But it is difficult to synthesize; the process can involve temperatures of 200 to 500 degrees Celsius and a crushing 10 times atmospheric pressure, says Zhi Li, a materials engineer at the University of Alberta, who was not involved in the study.

To circumvent this problem, Sawyer and her colleagues devised a new synthesis technique by capitalizing on *Shewanella oneidensis*'s anaerobic respiration. When this bacterium breathes air, it eventually transfers electrons to oxygen atoms. But in an anaerobic environment, the same organism can transfer electrons to particular metal compounds instead, says James Dylan Rees, a bioelectrical engineer at Rensselaer and the paper's first author. After "some trial and error" to determine the best metal compounds to use, Rees says, the team placed them with the bacteria in a mostly airless bottle. The bacteria then delivered their electrons to the compounds during respiration, creating MoS_2 nanoparticles as a by-product over the course of two weeks.

Li says he likes how the new method suggests a sustainable way to make MoS_2 at room temperature. If it is to be used reliably in electrical devices such as sensors and batteries, however, he notes that it is important to be able to control the uniformity of the material's repeating pattern of atoms. Sawyer says her team still needs to work on this aspect of the process—a challenging task when dealing with living bacteria.

But the future for synthesizing materials using bacteria is bright, she adds: "We're just really scratching the surface of what's possible." —*Karen Kwon*

Douglas O. Linder is a professor of law at the University of Missouri–Kansas City and creator of the Famous Trials Web site. He tries to write a poem every day, often having to do with the periodic table. He began his collection of elements years ago and by now has a little bit of *almost* everything.



The Noble Gases

High-born, not like those other elements,
The common riffraff, the ones
All too ready to mix it up.

From the right tower of the periodic table
They appraise their inferiors,
Arrayed in colored boxes as far as they can see.

Dancing lightly on the parapet,
Helium waves her party balloons
Of yellow, red, and blue.

A level down, in her flaming orange-red dress,
Neon shows a leg and shouts into the darkness
Her cry of freedom.

Argon chats with his neighbor below,
Krypton explaining again she's not a planet
That exploded, nor a danger to anyone, caped or not.

Flashy and rakish (but naturally so), Xenon
Flaunts his electric suit of lavender,
Nearly blinding all who look in his direction.

Radon draws something from his invisible pocket,
Bows, and casts seeds on the unaware,
Bids them gently into that good night.

And on the ground floor, Oganesson blinks out,
Half her life gone in less than a millisecond,
Happy to be in a poem—or in anything at all really.

CHRISTOPHER GRIFFITH *Trunk Archive*

Claudia Wallis is an award-winning science journalist whose work has appeared in the *New York Times, Time, Fortune* and the *New Republic*. She was science editor at *Time* and managing editor of *Scientific American Mind*.

Your Brain on Yoga

Medical scans hint that this ancient mind-body practice may boost neural health

By Claudia Wallis

I'll be honest: I'm something of a yoga nut. I've practiced for decades and recently became a certified yoga teacher. But, to be honest again, some of the health claims I've heard about yoga make me squirm. Does yoga really fix poor digestion? How on earth can it regulate thyroid function? In yoga classes, I sometimes struggle to calm my mind when a teacher invites us to do the anatomically impossible: "Breathe into your kidneys."

Yoga is deeply linked to traditional Eastern medicine and a view of the body as a system of energy channels and nexuses—a perspective that does not easily align with Western medicine. But since the start of this century, scientific research on yoga has exploded. Many recent studies assess yoga as a "complementary therapy" to be used alongside other treatments for problems such as back pain, depression, anxiety and arthritis. Such research often has found that the practice can help. Still, yoga studies tend to be of uneven quality, often relying on self-reported survey data. For that reason, I was struck by a 2019 review paper that focused on a more objective measure: brain scans. Though far from definitive, the findings hint that the practice may improve brain health, and they indicate a way to bring yoga and science more convincingly together.

The review, led by Neha Gothe, director of the Exercise Psychology Lab at the University of Illinois at Urbana-Champaign, examined 11 peer-reviewed papers that used various types of brain scans to assess the impact of yoga practice on the brain. Gothe and her colleagues limited their review to studies in which all three major elements of yoga were included: the physical poses, breathing exercises, and meditation or mindfulness. Six of the studies compared the brains of longtime practitioners to "yoga-naive" people who were typically matched by age, health, and fitness or level of physical activity. Five examined yoga as an intervention, scanning the brains of subjects before and after they were randomly assigned to a defined period of yoga practice or a control group.

Gothe admits that this is a "nascent field," and most of the studies were small. Yet despite varied populations, three patterns emerged with some consistency: yoga practice could be linked to increased gray matter volume in the hippocampus, a key structure for memory; increased volume in certain regions of the prefrontal cortex, the seat of higher-order cognition; and greater connectivity across the default mode network. This network plays a role in processing memories and emotions and "what we call self-referential processing—processing information about yourself," explains Jessica Damoiseaux, a cognitive neuroscientist at Wayne State University and co-author of the review paper. The significance of having more gray matter volume in these regions is not entirely clear, she says, but "it suggests there may be more connections between neurons, which can indicate better functioning."

Damoiseaux's research focuses on aging-related changes in the brain, and she notes that the structures that seem to be beefed up by yoga are ones that tend to shrink with aging, especially in people with dementia. The greater volumes linked to yoga are similar to those seen in studies of aerobic exercise. This raises a question: Is there really anything special about yoga, with its meditative components, or is it just another brain-preserving workout?

At this point it's hard to say. "The nice thing about yoga is that it combines a whole bunch of things that are good for you," but "that makes it messy to study," observes Catherine Bushnell, a senior investigator at the National Center for Complementary and Integrative Health, part of the National Institutes of Health. In the small observational studies that have been done, it is difficult to establish a cause-effect relationship between yoga and changes in brain anatomy and function. In her own work, for instance, Bushnell has found that veteran yoga practitioners have an increased tolerance for pain compared with non-yogis, and tolerance is associated with increased gray matter in a region called the insular cortex. But she cannot say that yoga is directly responsible. "It could be something about your personality that makes you want to do yoga, and that same personality factor could contribute to more gray matter," she says.

Clearer answers will come with better studies that build on the smaller experiments. Gothe, for example, recently received a federal grant for a study that will randomly assign 168 older adults to six months of classes of yoga, aerobic exercise, or stretching and strengthening. The goal is to compare the impact of the different regimens on brain anatomy and cognitive performance. Says Bushnell: "It's exactly the kind of trial we need." SA

Illustration by Fatinha Ramos

AN ECOSYSTEM TO IMPROVE CANCER CARE

A conversation with **CHATRICK PAUL,** head of U.S. oncology at AstraZeneca

Although many associate better cancer care with new treatments, advanced therapies are just one piece of the puzzle. Chatrick Paul, who oversees the U.S. oncology business at AstraZeneca, says the often overlooked cancer-care ecosystem is another. Through policy roundtables, an awards program and digital partnerships, Paul and his colleagues are building and supporting a nationwide community of healthcare professionals, policy-makers and patient advocates dedicated to improving the lives of those affected by cancer.

When looking at oncology, how is AstraZeneca going beyond the medicine to support patients diagnosed with cancer?

AstraZeneca's ambition is to one day eliminate cancer as a cause of death. We realize that we are only one piece of the puzzle in delivering on this ambition, and that we cannot do this alone. We must come together as a multidisciplinary community to realize meaningful change and to truly impact cancer care in our country.

How has this cohesive vision of care been impacted by COVID-19?

COVID-19 has had a significant impact on the delivery of care and has reinforced the need to address urgent issues for those who are living in underserved urban and rural parts of the country. Applying what we have learned in identifying and treating COVID-19, we can better equip ourselves to drive awareness and adoption of testing and diagnostics for the treatment of cancer. Similar to treating the virus, early identification and treatment of cancer may provide the best chances of treating to cure. This can only be done by ensuring pathology capabilities are available and appropriately resourced. It's with this in mind that we are working to build stronger relationships with advocacy groups and research institutions to improve diversity in clinical trials and showcase real-world evidence in addressing the needs of all patients.

AstraZeneca's YOUR Cancer program launched at the end of 2018. Can you share an update on the program?

YOUR Cancer is a community engagement program that spotlights the difference-makers of cancer care who are working to realize tangible change for patients. Through the program, we are supporting a nationwide oncology community dedicated to improving the lives of those affected by cancer.

Now in its third year, the YOUR Cancer program seeks to convene patient-advocacy organizations, professional societies, policy-makers, healthcare professionals and many more to identify and drive awareness and action on areas where change will be the most impactful for patients. With the community, we're working to identify the areas of greatest need which may include testing and diagnostics, early intervention, precision medicine, access and health equity.

You recently held the second annual Cancer Community — C2 — Awards. Can you explain the program and how it serves to realize positive change across the country?

The Cancer Community, or C2, Awards recognize the true change-makers in cancer care — the passionate individuals and organizations who are making a difference in the lives of those affected by cancer. This year, we received more than 130 nominations from across 31 states, highlighting just how much incredible work is being done in the fight against cancer. Nominations were reviewed by an esteemed panel of community leaders, and the ceremony recognized the work of 10 inspiring individuals and organizations. This year's ceremony was held virtually, but carried through the spirit of celebration, collaboration, networking and comradery as together we all hope for a world without cancer.

How else has the YOUR Cancer program brought together the cancer ecosystem to impact change?

In addition to the C2 Awards, the YOUR Cancer program seeks to raise awareness and drive action on key priorities for the cancer community in three ways: hosting community roundtable discussions; opening forums to discuss cancer care on a national stage; and ensuring relevant and accurate information is shared across digital platforms.

With the community, we've convened state-level policy discussions to identify and address barriers to care. A great example of the forward action taking place can be seen in California where work resulted in legislation being introduced to prohibit prior authorization for biomarker testing, eliminating unnecessary delays for patients who are trying to access appropriate treatment.

We've also brought the cancer conversation to the main stage, driving awareness and action where change is needed most. Just recently, we partnered with the Personalized Medicine Coalition to host a discussion focused on precision medicine as part of *The Economist's* War on Cancer series and we've held panel discussions during the annual *Washington Post* Chasing Cancer Summit. During each, we partnered with oncology leaders to discuss the areas where we can come together to make meaningful change and identify potential solutions to current challenges or barriers to cancer care.

We're also working with more than 50 partner organizations across digital platforms to share resources on community support programs, disease information and advocacy efforts. All of our work aims to provide patients with the information that they may need — emphasizing their central role in the oncology ecosystem.

To learn more about the YOUR Cancer program and the C2 Awards, visit www.YourCancer.org

AstraZeneca





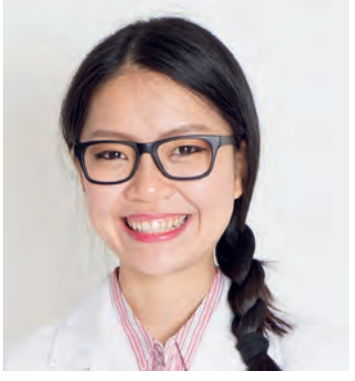

YOUR *cancer*

Learn More

YourCancer.org











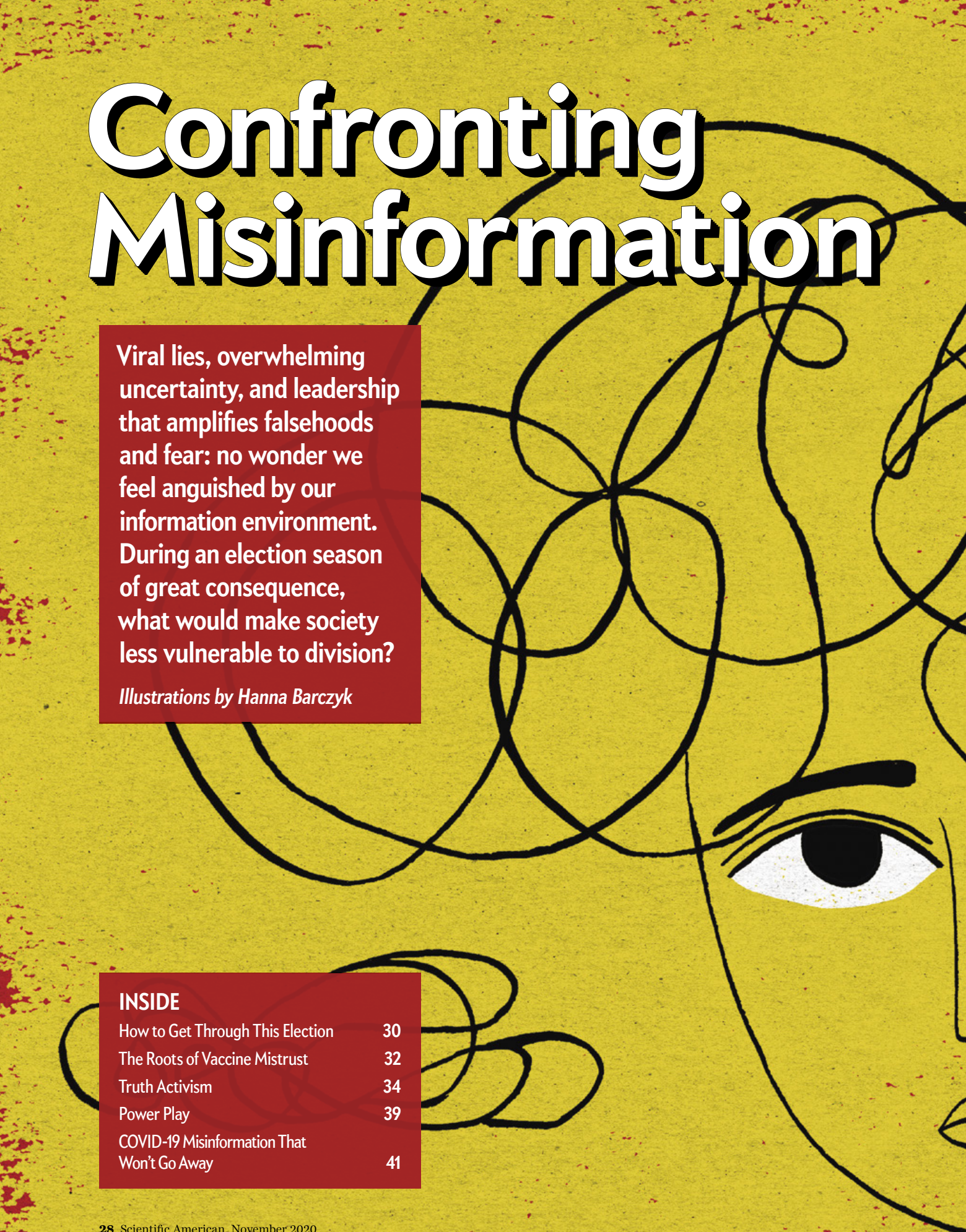


AstraZeneca

Confronting Misinformation

Viral lies, overwhelming uncertainty, and leadership that amplifies falsehoods and fear: no wonder we feel anguished by our information environment. During an election season of great consequence, what would make society less vulnerable to division?

Illustrations by Hanna Barczyk



INSIDE

How to Get Through This Election

By Claire Wardle

IN AUGUST, TWITTER CEO JACK DORSEY WAS INTERVIEWED ON THE *NEW YORK TIMES* PODCAST THE DAILY, where he was asked explicitly what his company will do if President Donald Trump uses Twitter to declare himself the winner of the 2020 election before the results have been decided. Dorsey paused, then provided a vague answer about learning lessons from the confusion that occurred in 2000 with the Florida recount and working with "peers and civil society to really understand what's going on." It was 88 days before the election, and my heart sank.

For those of us who study misinformation and investigate online efforts to interfere with democratic processes around the world, this election feels like our Olympics. It can be hard to remember just how different attitudes around the threat of false and misleading information were back in November 2016, when, two days after the presidential election, Mark Zuckerberg famously claimed that it was "crazy" to suggest that fake news had affected the outcome. Now a misinformation field has emerged, with new journals inspiring cross-disciplinary research, millions of dollars in funding spent on nonprofits and start-ups, and new forms of regulation from the European Union Code of Practice of Disinformation to U.S. legislation prohibiting so-called deepfakes.

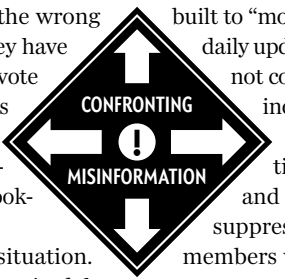
Planning for the impact of misinformation on the 2020 election has taken the form of a dizzying number of conferences, research projects and initiatives over the past four years that warned us about the effects of rumors, conspiracies and falsehoods on democracies.

Illustration by Hanna Barczyk

Claire Wardle is director of First Draft, an organization that conducts research and leads global trainings for reporting on and countering misinformation. Her last article for *Scientific American* was about the techniques of media manipulation.

Recent months were supposed to be the home stretch. So when Dorsey failed to give a concrete answer to a question about a highly likely scenario, it felt like watching a teammate fall on their face when they should have been nailing the dismount.

Every platform, newsroom, election authority and civil society group could have a detailed response plan for a number of anticipated scenarios—because we have seen them play out before. The most common form of disinformation is that which sows doubt about the election process itself: flyers promoting the wrong election date, videos of ballot boxes that look like they have been tampered with, false claims about being able to vote online circulating on social media and in closed groups on WhatsApp. The low cost of creating and disseminating disinformation allows bad actors to test thousands of different ideas and concepts—they are just looking for one that could do real damage.



We have not grappled with the severity of the situation. Social media platforms seem to have only recently recognized that this election might not end neatly on November 3. Nonprofits whose employees are exhausted after months of COVID-related misinformation work are still scrambling for resources. The public has not been adequately trained to manage the onslaught of misinformation polluting their feeds. Most newsrooms have not run through scenarios to practice how they will cover, say, bombshell leaks in the run-up to Election Day or after the election, when the outcome might be disputed. In the spring of 2017 France saw #macronleaks, the release of 20,000 e-mails connected to Emmanuel Macron's campaign and financial history two days before the election. Because of a French law that prohibits media mentions of elections in the final 48 hours of the campaign, the impact was limited. The U.S. does not have such protections.

The panic is palpable now. My e-mail inbox is full of requests from platforms to join belatedly assembled task forces and from start-ups wondering whether some technology could be quickly built to "move the needle" on election integrity. There are near-daily updates to platform policies, but these amendments are not comprehensive, lack transparency and have not been independently assessed.

Ultimately the rise of misinformation, polarization and emotion-filled content is our new reality, and the biggest threat we face in this moment is voter suppression. So rather than "muting" friends and family members when they post conspiracy theories on Facebook, start a conversation about the serious damage that rumors and falsehoods are doing to our lives, our health, our relationships and our communities. Do not focus on the veracity of what is being posted; use empathetic and inclusive language to ask *how* people are voting. No one should be shamed for sharing misinformation because we are all susceptible to it—especially now, when our worlds have been turned upside down and many of us are operating in fight-or-flight mode. To avoid losing ourselves in the noise, we have to help one another adapt. SA

Zakiya Whatley is a scientist and educator. She is co-host of Dope Labs Podcast and manages the University of Maryland's Biological Sciences Graduate Program. Whatley has a Ph.D. in genetics and genomics from Duke University.

Titilayo Shodiya is an engineer originally from Maryland. She is co-host of Dope Labs Podcast and is deputy quality manager of the National Institute of Standards and Technology. Shodiya has a Ph.D. in mechanical engineering and materials science from Duke University.

The Roots of Vaccine Mistrust

It's not just "antiscience" thinking

By Zakiya Whatley and Titilayo Shodiya

IN THE FACE OF NEARLY SEVEN MILLION INFECTIONS AND 200,000 DEATHS, many Americans refuse to wear masks because they don't *feel* the coronavirus is real. Even some of those who *believe* the virus exists are not concerned about getting sick.

How did this happen? Putting political ill will aside for a moment, the conflicting messaging that persisted from February through the summer could confuse even the most diligent information seeker. Recommendations from credible organizations swung like a pendulum. It sounded something like this: *Coronavirus is not a threat to America. The CDC is requiring quarantine for any international travelers. Don't touch surfaces. You don't need a mask. The CDC isn't requiring quarantine for travelers. Actually you do need to wear a mask, and surfaces aren't as risky.*

It is no surprise then that the public is split on expectations for how we need to deal and recover, both collectively and individually. Yet even among those who consider COVID-19 a real concern, there is uneasiness around the most promising solution to the pandemic: a vaccine. In an AP-NORC poll in mid-May, fewer than 50 percent of Americans surveyed said they would commit to getting a coronavirus vaccine whenever it becomes available. Although self-reported behavior does not always strongly correlate with actual behavior, other polls have since revealed similar sentiments.

It is tempting for public health communicators to dismiss those who are refusers or hesitant by broadly labeling them as conspiracy theorists or misinformed skeptics who would come around if given the facts. But mistrusting the coronavirus vaccine process—from development to trials to distribution—cannot merely be dismissed as "antiscience" thinking. It is not just an outcome of this moment's political polarization and dangerous misinformation coming from the highest levels of leadership.

Even though vaccines have virtually eliminated the risk of many preventable diseases, there has been an increase in refusal and hesitancy over the past two decades. Typically vaccine refusal is most prevalent in wealthy, white areas, but polls that seek to understand the pending coronavirus vaccine indicate high levels of hesitancy and refusal among marginalized communities, too. In fact, these groups appear to be the most skeptical, with only a quarter of Black respondents and 37 percent of Hispanic respondents in the AP-NORC poll saying they would commit to getting the vaccine whenever it is available. Considering that Black, Hispanic and Indigenous communities are at the highest risk of infection and are overrepresented in COVID-19 deaths, this result may look like a curious discrepancy. But it is not hard to understand these groups' caution and, in some cases, their downright refusal to engage with public health recommendations when one considers the historical racism embedded in the fabric of the medical systems and the harm suffered at the hands of biased science.

Exploring the more nuanced questions of how science and society are intertwined is central to our editorial strategy for Dope Labs, a podcast we created in 2019 to expand the notions of scientific communication and the scientific community. There are more than 30 million podcast episodes, yet even with this saturation, so much of the listener landscape in the U.S. overindexes on whiteness, wealth and education. Our goal is to center those who are most often excluded from the science narrative. This means our episodes explore the physics and chemistry of *Black Panther* and the rest of the Marvel Cinematic Universe when there is a new film release; highlight the effects of settler colonialism on Indigenous people and ecology at Thanksgiving; and connect racial justice movements with the fight against carbon emissions when we discuss climate change.

In a recent episode with author Angela Saini, we focused on the history of scientific racism. Through this lens, distrust of vaccines and scientific interventions is not without cause. Revisit the era of involuntary

sterilization, a tactic the U.S. eugenics movement used to eliminate the reproduction of those deemed "unfit." These procedures targeted Black, Indigenous and Latina women, along with those labeled "feebleminded." Contrary to claims by scientists who supported eugenics, the factors used to determine if a person was "unfit" were strongly correlated with their economic status, not their genetics. Consider, too, the echoes of the Tuskegee syphilis study, when hundreds of African-American men with syphilis were recruited by the U.S. Public Health Service in 1932 in exchange for free medical care. Even after a viable antibiotic treatment became available in 1947, these men were given only placebos for decades longer, just so the researchers could observe how bad the disease could get as it progressed.

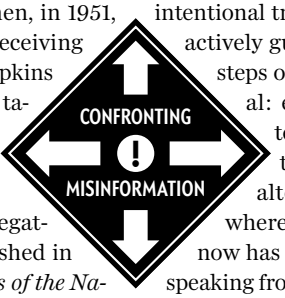
It is also reasonable that people are questioning the motives of the pharmaceutical industry or wondering whether a vetted coronavirus vaccine may already exist when scientists at elite universities are making their own "citizen vaccines" and administering it to themselves and to their colleagues. Meanwhile the general public waits for an official vaccine as people working essential jobs continue to die.

Consider other conspiracy theories that have circulated about potential vaccines, such as the fear that the injection will contain surveillance microchips. It is not so far-fetched to believe rumors that scientists will take people's most private information without permission while administering care when, in 1951, while Henrietta Lacks was receiving cancer treatment at Johns Hopkins Hospital, a tissue sample was taken without her knowledge, facilitating a significant body of research.

Medical racism is not relegated to the past. A study published in September in the *Proceedings of the National Academy of Sciences USA* surveyed 1.8 million births in the U.S. and found that the Black newborn mortality rate is three times higher when white doctors are delivering the child compared with Black doctors. Although the driving mechanism is unclear, the results—especially when combined with negative personal experiences in medical settings—are enough to make people doubt that doctors treat everyone with the same standard of care.

The people and institutions responsible for designing the communication around the coronavirus vaccine have to consider this broad backdrop if we want to get COVID-19 under control. Validating the ways in which the American people, and marginalized groups in particular, have sometimes been misled, mistreated and misunderstood at the hands of "science" is the first step in regaining their trust. There is no shortage of interests who seek to do harm by manipulating the public conversation and exploiting the legacy of medical racism with messages designed to invoke anger and fear. Public health officials who want to advocate for clarity need to understand these same vulnerabilities and address them head-on rather than ignoring them.

But what does this look like in practice? Anthony Fauci appears to subscribe to the "never say no" approach to communication, stepping into less familiar media formats where the audiences—whether deemed scientific or not—already exist: Lil' Wayne's Young Money Radio, Instagram Live with Matthew McConaughey and Khan Academy's YouTube. There is still a need for more diverse voices and unconventional storytelling approaches. We have received feedback that Dope Labs is too casual or not *really* a science podcast because we refuse to use jargon. But this is by design. We don't need more content that follows the same style; we want people to reconsider why credibility is assessed based on the presenter's voice, background and tone.



Science communicators should also use intentional transparency, where they proactively guide the public through the steps of vaccine design and approval: explain efficacy and safety testing; reassure during routine interruptions that lead to altered schedules; and admit where the very system we rely on now has failed in the past. Instead of speaking from a place of removed authority, communication works best when it validates the audience's fears and concerns. It focuses on the paths we are taking to avoid repeating previous mistakes—not as an afterthought or vague platitude but as a core part of the message.

Like many disasters, the pandemic is highlighting the weaknesses in our systems and gaps in our skill sets. On the path to a vaccine, we cannot afford to cling to barriers that exclude people—especially those who are the most skeptical. SA

Illustration by Hanna Barczyk

Joan Donovan is an adjunct professor at Harvard Kennedy School and research director of the Shorenstein Center on Media, Politics and Public Policy. This piece is dedicated to the memory, research and activism of Jeffrey Juris (1971–2020).

Truth Activism

Twenty years ago Internet protest movements unwittingly paved the way for media manipulation to flourish online. Advocacy is the way out

By Joan Donovan

DURING THE 1999 WORLD TRADE ORGANIZATION (WTO) MEETING IN SEATTLE, TENS OF THOUSANDS of protesters took to the streets with banners and puppets to push back against economic globalization. They were met with a violent militarized suppression. At the same time, a small group of artist-activists called the Yes Men created a parody Web site pretending to be the WTO. Cloaked in its official logos and design, they made critical claims about the organization. This hoax was so successful it landed the Yes Men speaking engagements *as* the WTO at several conferences around the world. As the absurdity grew, viewers began to question what they saw—which was the point.

Realizing that they could pull off similar pranks using mimicry of official Web sites, the Yes Men made a career out of punching up, posing as the National Rifle Association, the *New York Times* and Shell, among many others. In an eerie foreshadowing of today's disinformation campaigns, these activists poked fun at George W. Bush's gaffes as a presidential candidate at GWBush.com.

Through spoofs, the Yes Men understood the power of the Internet as a new networked terrain where battles over truth could be fought. They played with the ambiguity of authenticity at a time when most Internet users were already skeptical of online content. The "culture jamming" tactic used by the Yes Men took its cue from Guy Debord and the so-called situationists of the 1960s, who advanced social and political critique. In the 1980s and 1990s culture jamming unified activists around a common cause and set of tactics, such as making minor edits of an advertisement to drastically change its meaning. This form of "artivism" was championed by *Adbusters,* a Canadian magazine that ran numerous anticorporate campaigns, most notably initiating the call to Occupy Wall Street in 2011. Simply modifying the slogan under a Nike swoosh to read "Just Buy It" was an effective way of reorienting consumers' ideas about what it meant to wear corporate logos as fashion.

Crucially for activists such as the Yes Men, the big reveal was the raison d'être for the hoax. The cognitive dissonance experienced by the reader or viewer was a clever strategy that opened the way for critical thinking. Once they produced that chasm of the mind, the real work would begin: convincing new audiences that these corporations were the real enemies of democracy and justice.

The Yes Men's tactics were a kind of media manipulation. For them and other activists, the Internet provided a means of knowledge transmission and a way to counter the credulity of the mainstream press and hold corporations to account. But the ingenuity of using the Internet as a canvas for mischief and critique worked a little too well. Just a couple of decades later technology companies have created a media ecosystem that allows governments, political operatives, marketers and other interested parties to routinely expose Internet users to dangerous misinformation and dupe them into amplifying it. There is mounting evidence of foreign operatives, partisan pundits, white supremacists, violent misogynists, grifters and scammers using imper-

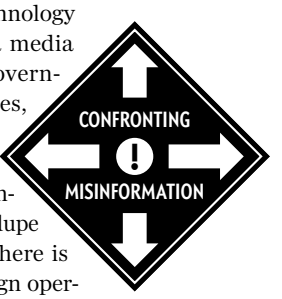


Illustration by Hanna Barczyk

sonation on social media as a way to make money, gain status and direct media attention. How did we end up in a situation where lies travel farther and faster than the truth?

The answer involves the promise of networked communication technology, the new data economy and the spiraling deluge of profitable strategic misinformation. We must admit that the truth is often emotionally boring and that the motivation to take action online through, say, sharing a video requires some combination of outrage, novelty and hope. But rather than proposing a set of solutions that involve tweaking social media systems, hunting down bots or insisting on verified identities, we can look to activism to understand how we got here—and how we could get out.

Fighting back involves dispatching with the ideology that technological platforms are democracy in action.

THESE DAYS it is difficult to remember that there was a time when what happened online was not so world-shattering. Back in the mid-1990s heyday of America Online, Internet users protected anonymity via screen names and cryptic profiles littered with song lyrics. Most would never have thought it safe to type a credit-card number into a Web site or share personal identifying information. Because bandwidth was limited and you were yoked to the telephone wire, going online meant stopping everything "in real life" and forming bonds out of shared interests or a desire to play backgammon on Yahoo Games. The Internet was a place you could go to be yourself or someone else. John Perry Barlow and other early Internet pioneers cheered that it was the "home of the mind" where neither bodies nor laws much mattered.

Because news was still expensive to create and its distribution largely remained in the hands of media moguls, the Internet was not considered a place to seek authoritative information. In the mid-1990s news organizations were contemplating "going digital," which mostly meant putting print articles online. There was no widespread fear that local news would disappear. If anything, it seemed like networked communications would produce the opposite outcome: any person with a connection could write about their community and interests and publish it for the world to see, anonymously or not.

I often joke that the Internet died the same day someone figured out how to get users to pay online for pizza delivery. As the Internet developed into a digital economy, verifiable identity was indispensable to the flows of commerce. Of course, the first widespread online commodity was pornography, which illuminates an important point: it is often not the whizbang of disruptive innovation that drives social change but the technological adaptation of the ordinary and mundane. As technology develops, so do humans; in adopting new technologies, people become part of a recursive circuit that changes themselves and the world around them.

Whereas the printing press was the platform that gave birth to a society of readers, the Internet fashioned everyone as a publisher. Early social-networking platforms such as LiveJournal, BlackPlanet, Friendster and MySpace were like self-service telephone books; they gave people the capacity to share stories and converse. Similarly, today's biggest Silicon Valley tech companies began from modest intentions, a desire to connect people for specific reasons.

Facebook built its base by maintaining exclusivity. It was social networking but only for the elite colleges. Its earliest version included a misogynistic feature where users could compare and rate fellow women students' attractiveness. YouTube began as an update on video dating, where the "you" in YouTube was an invitation for users to upload short videos talking about their perfect partner in the hopes of finding true love. Twitter was meant to function like group texts among co-workers but only seemed to find its purpose when the techno-elite of SXSW used it to enhance communication across an already technologically dense network. In that context, Twitter's character limit was celebrated as virtuous microblogging, where small strings of text were favored over the long-winded diatribes of traditional blogs. Each of these tools has evolved not just technologically but also culturally, as society passed through a phase of excitement into one of disillusionment.

Since their inception, big questions loomed about how social media companies could become financially lucrative. The search for profit drove decisions about expanding the user base, remodeling advertising and converting users into market value. Mobile technology and broadband accelerated the capabilities of tech companies to expand their services in new areas, including data harvesting. Personal data were seen as an artifact of time spent on these services, and by simply interacting, online users sloughed off enough residual data to energize a digital economy ravenous for every click, like, share and mouse movement to be aggregated and monetized.

Social-networking sites transformed into social media, where the business model was no longer just to connect people to people and litter those pages with ads but also to connect people to "content"—information, pictures, videos, articles and entertainment. The result was a digital economy built on engagement, where content farms making "clickbait" became the watchword of the Internet economy.

But not just junk news sites make money. By creating a content-rich environment, tech companies turned advertisers into customers and users into cattle to be milked. Behavioral data could be repackaged for purposes from marketing to research to political campaigning. Profit-sharing

models that made average users into content producers generated a so-called influencer culture, where entrepreneurial creators cultivated networks of followers and subscribers and then monetized them through donations, subscriptions or sponsored content. As personal data became a cash cow for social media companies, user experience could be tailored to prolong their time on sites.

The consequence, as we know well today, was the development of personalized information ecosystems. No longer did Internet users see the same information. Instead algorithmic echo chambers shaped individual news feeds and time lines to the extent that two people sitting side by side may receive very different recommendations based on their past behaviors online. Scams and grifts that would have been shut down if they were taking place on city streets, like selling counterfeit merchandise or running an illegal taxi company, flourished online.

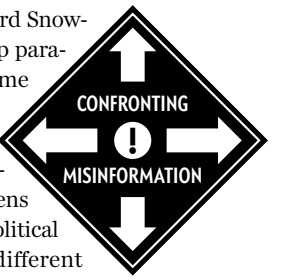
Yet technology companies shield themselves from accountability by claiming to be a humble set of rails on which information is shuttled from one place to another. Largely because of an early ideological commitment that cyberspace was no place at all, tech companies leveraged a metaphorical mirage, where jurisdiction in cyberspace is murky and accountability is elusive. While scholars of gender, race and technology, such as Lisa Nakamura of the University of Michigan, Alice E. Marwick of the University of North Carolina at Chapel Hill and T. L. Taylor of the Massachusetts Institute of Technology, routinely wrote about the dangers of divesting the Internet of a material existence, politicians and regulatory bodies failed to treat the Internet as a place where real damage could occur.

JUST PRIOR to the rollout of broadband in the 1990s, a hyperlocal model of media justice took shape through activist use of the Internet. Jeffrey Juris, an anthropologist of networked social movements, ethnographically studied how the anticorporate globalization movement of the late 1990s and early 2000s used every technology at its disposal to organize large summits to protest meetings of the WTO and International Monetary Fund. As Juris has written, the Zapatista movement's use of networked communication technology was the forerunner to large protest gatherings: insurgents used online networks to connect with other like-minded groups globally and to provide the international press with updates on the struggle for independence in Chiapas.

To plan the 1999 protest against the WTO in Seattle, activists relied on Web sites and e-mail lists to coordinate their tactics and to forge trust across borders. Juris wrote of this form of media activism in 2005 as he studied the development of a digital hub for citizen journalists calling itself Indymedia.org. He wrote that "Indymedia has provided an online forum for posting audio, video, and text files, while activists have also created temporary media hubs to generate alternative information, experiment with new technologies, and exchange ideas and resources. Influenced by anarchism and peer-to-peer networking logics, anti–corporate globalization activists have not only incorporated digital technologies as concrete tools, they have also used them to express alternative political imaginaries based on an emerging network ideal." This shared set of digital tools included Web site templates that could be quickly adapted and networked through a centralized repository. The rallying cry of Indymedia contributors became: "Don't Hate the Media, Become the Media!"

It was this same techno-optimism that later led activists to adopt Facebook, Twitter and YouTube alongside e-mail lists, SMS text groups and livestreaming during the so-called Arab Spring, the Occupy Movement and the early iterations of Black Lives Matter. These networked social movements were multiplatform in several senses of the word: they existed on computational infrastructure that referred to itself as a tech platform where activists offered an alternative political platform geared toward social justice.

Because activists were using this infrastructure to create widespread change, technology companies envisioned a new purpose for their products. To capture this momentum, companies such as Facebook and Twitter began to rebrand their products as tools for free speech. In this new marketing scheme, social media companies were likened to the digital streets or public square, and their products were framed as synonymous with democracy itself. In truth, the slipperiness of the term "platform" permitted companies such as YouTube, Facebook and Twitter to sidestep regulation and public-interest obligations that are typically applied to broadcast media.

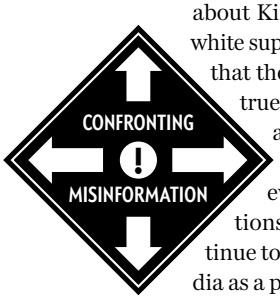


Then, in 2013, the Edward Snowden scandal revealed a deep paradox to the public: The same technology used by activists to foment social change was being used by governments to spy on their citizens and for corporations and political campaigns to carry out different kinds of experiments. (Shoshana Zuboff explored this theme in her 2019 treatise on surveillance capitalism.) Activists' participation on tech platforms was largely about using any means necessary to achieve a more just society. As the platforms' products changed, so, too, did their usefulness to other actors, such as police, news organizations, brands and politicians. By expanding their customer base to include all these types of professionals, tech companies diluted their reputation as a place for digital democracy and took on the sinister character of a panoptic media system—one bent on making a profit at the expense of users and anyone who threatened their growth.

THROUGHOUT THE 2000S the Yes Men continued to pull pranks through their form of digital activism. They devised a political education program, where many folks contemplated the use of hoaxing as a mechanism for social protest. Shenanigans undoubtedly make a lasting and memorable impression, but hoaxes and impersonation can backfire by giving false hope. No one likes to feel

manipulated or tricked, and the tactic received significant criticism from people who were truly victimized by corporations. In 2007, for example, the Yes Men impersonated Dow Chemical during an interview on the BBC where they took responsibility for the gas leak disaster in Bhopal, India, and promised $12 billion in reparations. This "news" was met with excitement that morphed into sadness and disappointment when victims found out that Dow actually did no such thing.

It was not only leftists creating convincing hoax sites in the 1990s. Jessie Daniels, a sociologist, has researched the myriad ways white supremacists have used "cloaked Web sites" to malign Martin Luther King, Jr., and other Black activists and groups, in ways similar to the tactics the FBI would use to plant stories about King. Networked factions of white supremacists are keenly aware that they cannot show up in their true form online. Whether they are remaining anonymous to avoid social stigma or evade hate crimes investigations, white supremacists continue to see the Web and social media as a political opportunity to convert new believers. As a result, they have innovated on strategies to hide their identities online to maximize reputational damage to their perceived opposition.



Now the field is open to any ideologically motivated group. Tactics include impersonating individual politicians, creating mass fake accounts, and coordinating the harassment of journalists and activists through the use of streaming platforms, chat rooms and message boards. Groups have also used automated posting to game algorithmic signals, as well as paid advertising tools to target vulnerable populations. Others have generated denigrating deepfakes. They also have adopted techniques to influence trending algorithms, as well as to circumvent content moderation.

Many of these techniques, such as the use of bots, were pioneered by advertising agencies, which understood that data were money and that the creation of fake engagement data could produce real profit. Now the generation of fake accounts and manipulated engagement are the means by which hoaxes are carried out.

Unlike the artist-activists who used hoaxes to reveal deeper truths about capitalist exploitation, these imposters use cloaking and pseudoanonymity to attack journalists, politicians and average users. My Harvard University colleague Brian Friedberg and I have written about the impact of "pseudoanonymous influence operations," wherein politically motivated actors impersonate marginalized, underrepresented and vulnerable groups to malign, disrupt or exaggerate their causes. Recently accounts run by white supremacists claiming to be antifascist activists were outed as impostors.

If and when operators of pseudoanonymous accounts are found out, there is no grand reveal of some larger social or political critique. Usually their goal is to trick journalists into smearing their opponent or to simply cause chaos. These disinformers quickly move on to the next potential media-manipulation campaign to advance their political agendas.

Eradicating these impostor tactics is possible, but it would require tech companies to admit that the design of their systems aids and abets media manipulators.

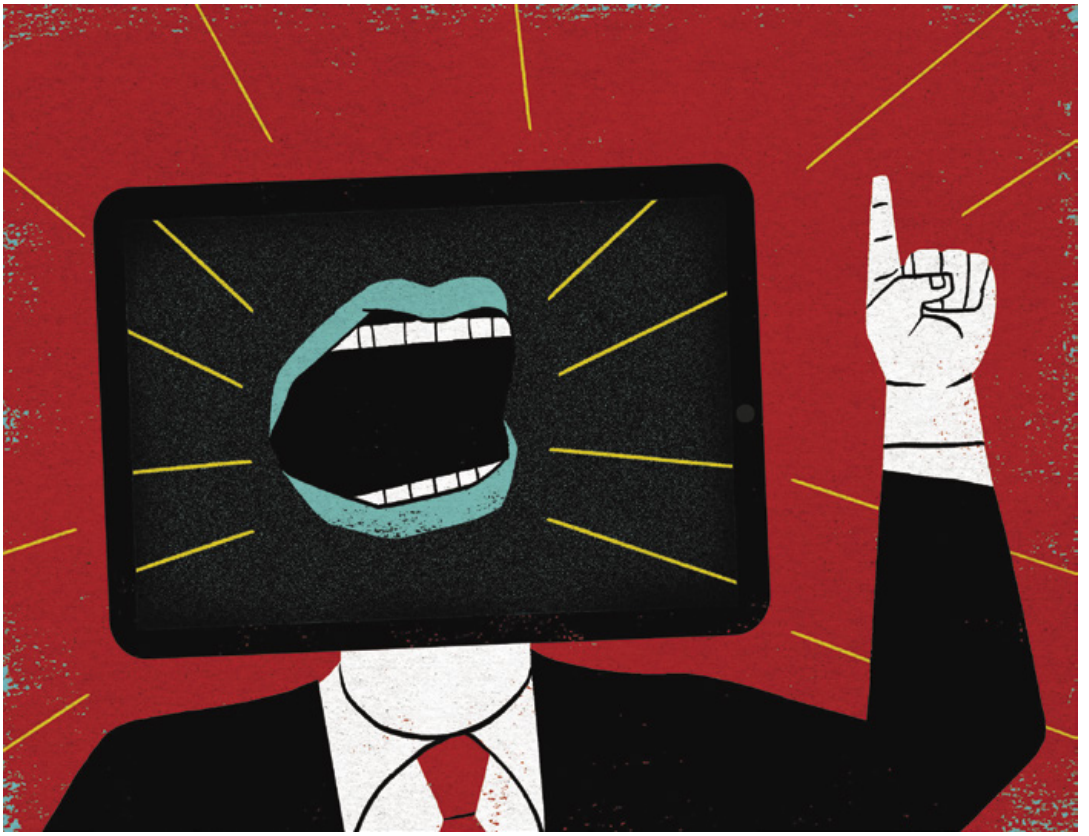
Indeed, we do not have an equal-opportunity media ecosystem. The anguish of seeing these tactics deployed time and time again to malign movements for justice illustrates that over the long term, they are effective only for those who want to advance short-term gains over long-term trust and safety. Many people believe they can spot false news and propaganda, but the reality is that it is much more difficult because the very design of social media and the incentives to plant misinformation are weighted in the favor of disinformers. In an environment where novel claims travel far and fast, the truth is at a serious disadvantage.

Because tech companies have been reticent to handle the information war playing out across their platforms, society at large pays the price. News organizations, as well as individual journalists, are investing huge amounts of resources to combat the problem. National security experts and academic research centers across the globe are creating content moderation software to monitor social media. Yet activists who have long endured damaging coverage by misinformed press are now called to defend their very existence from impostors—the disinformers who are deliberately stealing the moral authority and trust activists have built up over years of digital engagement.

For anyone who still cares deeply about the truth and people's access to it, fighting back involves dispatching with the ideology that technological platforms are democracy in action. They have shifted from connecting people to people to connecting people to information, tilting power toward those groups that have the most resources. They are also fundamentally businesses that have scaled without a plan for mitigating the harmful effects they have on society.

Redesigning social media for timely, local, relevant and authoritative information requires a commitment to design justice, which sees technology not as a neutral tool but as a means for building the worlds we want. As communication scholar Sasha Costanza-Chock of M.I.T. has researched, the process of design must adhere to an ethic of "nothing about us without us." For example, there would be no accountability on facial-recognition technologies without the activism of groups such as the Algorithmic Justice League, the research of AI Now, the political work of the A.C.L.U., and ordinary advocates showing their support online and off.

Activists are visionaries in the sense that they see materials not just as they are but for what they can become. In the early 2000s they transformed technology in new and exciting ways, but that era has passed. We can't stay swept up in "techno-nostalgia" for what once was or could have been. If we are going to survive our ailing social media ecosystem, the truth needs advocates. SA



Jen Schwartz is a senior features editor at *Scientific American*. She writes about how society is adapting (or not) to a rapidly changing world.

Power Play

Can live simulation games help journalists fight disinformation?

By Jen Schwartz

I AM NOT THE EDITOR IN CHIEF OF A PROPAGANDA FARM DISGUISED AS a far-right breaking news outlet. But one day last February, just before the world shut down, I got to play one.

About 70 journalists, students and digital media types had gathered at the City University of New York to participate in a crisis simulation. The crisis at hand was the 2020 U.S. presidential election. The game was designed to illuminate how we, as reporters and editors, would respond to a cascade of false and misleading information on voting day—and how public discourse might respond to our coverage. The exercise was hosted by First Draft, a research group that trains people to understand and outsmart disinformation.

After a morning workshop on strategies for reporting on conspiracy theories and writing headlines that don't entrench lies, the organizers split us up into groups of about 10 people, then gave each "newsroom" a mock publication name. Sitting around communal tables, we assigned ourselves the roles of reporters, editors, social media managers and a communications director. From our laptops we logged into a portal to access the game interface. It looked like a typical work desktop: There was an e-mail in-box, an intraoffice messaging system that functioned exactly like Slack, a microblogging platform that worked exactly like Twitter and a social feed that looked exactly like Facebook. The game would send us messages with breaking events, press releases and tips, and the feeds would respond to our coverage. Several First Draft staffers at a table were the "communications desk," representing any agency, person or company we might need to "call" to answer questions. Other than that, we received no instruction.

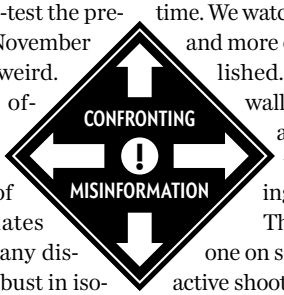
My newsroom was mostly made up of students from C.U.N.Y.'s Craig Newmark Graduate School of Journalism and other local universities. The organizers gave us a few minutes to define our newsrooms' identities and plan our editorial strategies. The room filled with nervous murmurings of journalists who wanted to fight the bad guys, to beat back misinformation and safeguard election day with earnest, clear-eyed coverage. But I had a different agenda, and I was the one in charge.

"Sorry, team," I said. "We're going rogue."

SIMULATIONS should include extreme scenarios if they are to properly scare people into preparing for the unexpected—into

updating protocols and rearranging resources or tripping certain automated processes when things go awry. Yet journalists and scientists tend to resist engaging with the outlandish. We dismiss sensational outcomes, aiming to wrangle expectations back into the realm of reason and precedent. In recent years that strategy has often left us reeling. A *Nature* article published this past August explained why the U.S. was caught flat-footed in its response to COVID-19: despite the fact that government officials, academics and business leaders have participated in dozens of pandemic simulations over the past two decades, none of the exercises "explored the consequences of a White House sidelining its own public health agency," wrote journalists Amy Maxmen and Jeff Tollefson.

The success of any scenario game, then, depends on the questions it raises. The game doesn't need to predict the future, but it does need to pry players away from the status quo, to expand their sense of what is possible. And to stress-test the preparedness of a newsroom on November 3, 2020, things needed to get weird.



Disinformation scholars often warn that focusing on the intent of influence operations or the sophistication of their techniques overestimates their impact. It's true that many disinformation tactics are not robust in isolation. But the targeted victim is fragile; pervasive anxiety and a deep social divide in America make us vulnerable to attacks from afar and within. And because it's cheap and easy for bad actors to throw proverbial spaghetti at social feeds, occasionally something sticks, leading to massive amplification by major news organizations. This was my goal as an editor in chief of unreality.

The simulation started off slowly. A tip came in through e-mail: Did we see the rumor circulating on social media that people can vote by text message?

As other newsrooms began writing explainers debunking SMS voting, I assigned a reporter to write a "tweet" that would enhance confusion without outright supporting the lie. After a quick edit, we posted: *We're hearing that it's possible to vote by text message. Have you tried to vote by SMS? Tell us about your experience!* It went up faster than any other content, but the social Web reacted tepidly. A couple of people called us out for spreading a false idea. So we dug in with another post: *Text message voting is the way of the future—but Democrats shut it down. Why are elites trying to suppress your vote? Story coming soon!*

We continued this pattern of baseless suggestions, targeted at whatever people on the feed seemed to already be worried or skeptical about. Eventually some of the other newsrooms caught on that we might not be working in good faith. At first they treated our manipulations as myths to debunk with fact-laden explainers. But our coverage kept getting dirtier. When an editor from a respectable outlet publicly questioned the integrity of my senior reporter, I threatened to take legal action against anyone who maligned her. "We apologize to no one!" I yelled to my team.

My staff was having fun wreaking havoc. The social platforms in the game were controlled by First Draft organizers (who, I later learned, meted out eight "chapters" of preloaded content), as well as manual input from the simulation participants in real time. We watched the feeds react with more and more outrage to the "news" we published. Our comms director stonewalled our competitors, who kept asking us to take responsibility for our actions, even forming a coalition to call us out.

Then a new tip appeared: someone on social media said there was an active shooter at her polling place. Everyone's attention shifted. The first newsroom to get a comment from the "local police" posted it immediately: *At this time, we are not aware of any active shooting threat or event. We are investigating.* While other teams shared the message and went to work reporting, I saw a terrible opening in the statement's inconclusiveness. "Let's question the integrity of the cops," I whispered maniacally to my team.

We sent out a post asking whether the report could be trusted. In a forest of fear, the suggestion that voters were at risk from violence was a lightning bolt. Social media lit up with panic. A celebrity with a huge following asked her fans to stay safe by staying home. My newsroom quietly cheered. We had found an editorial focus, and I instructed everyone to build on it. We "tweeted" a dozen times, occasionally promising an in-depth story that never arrived.

Once we were on a roll, I paused to survey the room. I watched the other teams spending all their energy on facts and framing and to-be-sures, scrambling to publish just one article debunking the misleading ideas we had scattered like dandelion seeds. We didn't even need to lie outright: maybe there *was* an active shooter! In the fog of uncertainty, we had exploited a grain of possible truth.

ABRUPTLY, the organizers ended the game. Ninety minutes had somehow passed.

I took stock of myself standing up, leaning forward with my hands pressed to the table, adrenaline rippling through my body. I had spent the previous year researching digital disinformation and producing articles on its history, techniques and impact on society. Intellectually I knew that people and groups wanted to manipulate the information environment for power or money or even just for kicks. But I hadn't understood how that felt.

I scanned the faces of my "colleagues," seeing them again as humans rather than foot soldiers, and flinched at the way they looked back at me with concern in their eyes.

Our debrief of the simulation confirmed that my newsroom had sabotaged the media environment on Election Day. "You sent the other newsrooms into a tailspin," First Draft's deputy director Aimee Rinehart later told me. She said I was the first person to co-opt the game as a "bad steward of the Internet," which made me wonder if future simulations should always secretly assign one group the role of wily propagandist.

It took hard alcohol and many hours for my nervous system to settle down. The game had rewarded my gaslighting with amplification, and I had gotten to witness the spread of my power, not just in likes and shares but through immediate "real-world" consequences.

Playing the bad guy showed me how the design of platforms is geared toward controlling minds, not expanding them. I'd *known* this, but now I *felt* why journalism couldn't compete against influence operations on the high-speed battlefield of social media—by taking up the same arms as the outrage machine, we would become them. Instead we could strengthen our own turf by writing "truth sandwich" headlines and service articles that anticipate the public's need for clarity. Because ultimately the problem wasn't about truths versus lies or facts versus falsehoods. It was about stability and shared reality versus disorientation and chaos. And in that day's simulation of the 2020 election, chaos had won by suppressing the vote. SA

Tanya Lewis is an associate editor covering health and medicine for *Scientific American*.

COVID-19 Misinformation That Won't Go Away

The most insidious falsehoods about the novel coronavirus—and why people believe them

By Tanya Lewis

1 The virus was engineered in a laboratory in China.

BECAUSE THE PATHOGEN FIRST EMERGED IN WUHAN, CHINA, PRESIdent Donald Trump and others have claimed, without evidence, that it started in a lab there, and some conspiracy theorists believe it was engineered as a bioweapon.

WHY IT'S FALSE: U.S. intelligence agencies have categorically denied the possibility that the virus was engineered in a lab, stating that "the Intelligence Community … concurs with the wide scientific consensus that the COVID-19 virus was not man-made or genetically modified." Chinese virologist Shi Zhengli—who studies bat coronaviruses and whose lab Trump and others have suggested was the source of COVID-19—compared the pathogen's sequence with those of other coronaviruses her team had sampled from bat caves and found that it did not match any of them. In response to calls for an independent, international investigation into how the virus originated, China has invited researchers from the World Health Organization to discuss the scope of such a mission.

WHY PEOPLE BELIEVE IT: People want a scapegoat for the immense suffering and economic fallout caused by COVID-19, and China—a foreign country and a competitor of the U.S.—is an easy target. Accidental lab releases of pathogens do sometimes occur, and although many scientists say this possibility is unlikely, it provides just enough legitimacy to support a narrative in which China intentionally engineered the virus to unleash it on the world.

2 COVID-19 is no worse than the flu.

Since the beginning of the pandemic, Trump has lied about the disease's severity, saying it is no more dangerous than seasonal influenza. Trump himself admitted to journalist and author Bob Woodward in recorded interviews in early February and late March that he knew COVID-19 was more deadly than the flu and that he wanted to play down its severity.

WHY IT'S FALSE: The precise infection fatality rate of COVID-19 is hard to measure, but epidemiologists suspect that it is far higher than that of the flu—somewhere between 0.5 and 1 percent, compared with 0.1 percent for influenza. The Centers for Disease Control and Prevention estimates that the latter causes roughly 12,000 to 61,000 deaths per year in the U.S. In contrast, COVID-19 had caused 200,000 deaths in the country as of mid-September. Many people also have partial immunity to the flu because of vaccination or prior infection, whereas most of the world has not yet encountered COVID-19. So no, coronavirus is not "just the flu."

WHY PEOPLE BELIEVE IT: Their leaders keep saying it. In addition to his repeated false claims that COVID-19 is no worse than the flu, Trump has also said—falsely—that the numbers of deaths from COVID-19 are exaggerated. In fact, reported deaths from COVID-19 are likely an undercount.

3 You don't need to wear a mask.

Despite a strong consensus among public health authorities that masks limit transmission of coronavirus, many people (the president included) have refused to wear one. Georgia's governor Brian Kemp went so far as to sign an executive order banning city governments from implementing mask mandates. He even sued Atlanta's mayor Keisha Lance Bottoms when she instituted one, although he has since dropped the lawsuit. Nevertheless, as coronavirus cases spiked around the U.S. during the summer, even states that were once staunch holdouts implemented mask orders.

WHY IT'S FALSE: Masks have long been known to be an effective means of what epidemiologists call source control (preventing a sick patient from spreading a disease to others). A recent analysis published in the *Lancet* looked at more than 170 studies and found that face masks can prevent COVID-19 infection. It has also been widely established that people can be infected with and spread COVID-19 without ever developing symptoms, which is why *everyone* should wear a mask to prevent asymptomatic people from spreading the virus.

WHY PEOPLE BELIEVE IT: Early guidance on masks from the CDC and the WHO was confusing and inconsistent, suggesting that members of the general public did not need to wear masks unless they had symptoms of an infection. The guidance was in part

driven by a shortage of high-quality surgical and N95 masks, which the agencies said should be reserved for health care workers. Even though face coverings are now mandated or recommended in many states, some people refuse to wear one because they consider it emasculating or a violation of their civil liberties.

4 Wealthy elites are using the virus to profit from vaccines.

In a book and in the conspiracy theory film *Plandemic,* Judy Mikovits, who once published a high-profile but eventually retracted study on chronic fatigue syndrome, makes the unsubstantiated claim that National Institute of Allergy and Infectious Diseases director Anthony Fauci and Microsoft co-founder Bill Gates could be using their power to profit from a COVID-19 vaccine. She also asserts without evidence that the virus came from a lab and that wearing masks "activates your own virus." An excerpt from the film was widely shared by anti-vaxxers and the conspiracy theory group QAnon. The video was viewed more than eight million times on YouTube, Facebook, Twitter and Instagram before it was taken down.

WHY IT'S FALSE: There is no evidence that Fauci or Gates has benefited from the pandemic or profited from a vaccine. In fact, Fauci has sounded alarms throughout the pandemic about the risks of the virus, and Gates has a long history of philanthropy geared toward eliminating communicable diseases. Mikovits's claims about the virus's origin and the efficacy of masks also have no scientific support.

WHY PEOPLE BELIEVE IT: Wealthy or influential figures such as Gates and Fauci are often the target of conspiracy theories. Trump has at times attacked Fauci, a member of his own coronavirus task force, calling him an "alarmist." Some of the president's followers may find it more palatable to believe that Fauci is exaggerating the severity of the outbreak than to acknowl-

Illustration by Hanna Barczyk

edge the Trump administration's failure to contain it.

5 Hydroxychloroquine is an effective treatment.

When a small study in France suggested the malaria drug hydroxychloroquine might be effective at treating the disease, Trump and others seized on it. The study is now widely criticized, but some people have continued to tout the medication despite growing evidence that it does not benefit COVID-19 patients. In a tweet, Trump called the hydroxychloroquine treatment "one of the biggest game changers in the history of medicine," and he has mentioned it repeatedly in his public coronavirus briefings, continuing to hype the drug. In late July he retweeted a video featuring Stella Immanuel, a Houston, Tex.–based physician (who has made questionable assertions in the past, including that doctors had used alien DNA in treatments and that demons cause certain medical conditions by having sex with people in their dreams), claiming that hydroxychloroquine is an effective treatment for COVID-19. The video was viewed tens of millions of times before social media companies took it down.

WHY IT'S FALSE: Several studies have shown that hydroxychloroquine does not protect against COVID-19 in those who are exposed. The Food and Drug Administration initially issued an emergency use authorization for the drug, but the agency later warned against its use because of the risk of heart problems and ultimately revoked its authorization. And in June the National Institutes of Health halted its clinical trial of the medication, stating that although it was not harmful to patients, it did not provide any benefit.

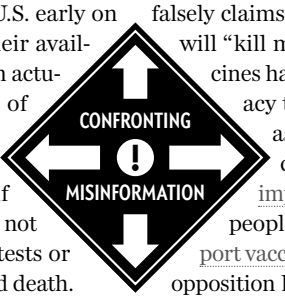
WHY PEOPLE BELIEVE IT: Initial reports suggested hydroxychloroquine might be a potentially promising drug, and people are most likely to believe the first things they learn about a topic, a phenomenon called anchoring bias. And because Trump has repeatedly claimed that the drug is effective, his supporters may be more likely to believe reports that confirm their views rather than those that challenge them.

6 Increases in cases are the result of increased testing.

As coronavirus cases surged in the U.S., Trump frequently claimed that the spikes were merely the result of more people being tested. He has tweeted that "without testing … we would be showing almost no cases" and has said in interviews that the reason numbers appear to have gone up is that testing has increased.

WHY IT'S FALSE: If this scenario were true, one would expect the *percentage* of positive tests to decrease over time. But numerous analyses have shown the opposite. The rate of positive tests rose in many states (such as Arizona, Texas and Florida) that had big outbreaks this past summer, and it decreased in states (such as New York) that controlled their outbreaks. In addition, hospitalizations and deaths increased along with cases, providing more evidence that the national increase in positive tests reflected a true increase in cases.

WHY PEOPLE BELIEVE IT: There was a severe shortage of tests in the U.S. early on during the pandemic, and their availability has increased (although actual testing remains far short of what is needed). It is logical to wonder whether more cases are simply being detected—if you look only at total cases and not at the proportion of positive tests or the rates of hospitalization and death.



7 Herd immunity will protect us if we let the virus spread through the population.

Early on in the pandemic, some speculated that the U.K. and Sweden were planning to let the coronavirus circulate through their populations until they reached herd immunity—the point at which enough people are immune to the virus that it can no longer spread. (Both nations' governments have denied that this was their official strategy, but the U.K. was late to issue a full lockdown, and Sweden decided against widespread restrictions.)

WHY IT'S FALSE: There is a fundamental flaw with this approach: experts estimate that roughly 60 to 70 percent of people would need to get COVID-19 for herd immunity to be possible. Given the high mortality rate of the disease, letting it infect that many people could lead to millions of deaths. That tragedy is what happened during the 1918 influenza pandemic, in which at least 50 million people are thought to have perished. The U.K.'s COVID-19 death rate is among the world's highest. Sweden, for its part, has had significantly more deaths than neighboring countries, and its economy has suffered despite the lack of a shutdown.

WHY PEOPLE BELIEVE IT: They want to get back to normal life, and without a widely available COVID-19 vaccine, the only way to achieve herd immunity is to let a substantial number of people get sick. Some have speculated that we may have already achieved herd immunity, but population-based antibody studies have shown that even the hardest-hit regions are far from that threshold.

8 A COVID-19 vaccine will be unsafe.

Worrying reports have emerged that many people may refuse to get a COVID-19 vaccine once it is available. Conspiracy theories about potential vaccines have circulated among anti-vaxxer groups and in viral videos. In *Plandemic,* Mikovits falsely claims that any COVID-19 vaccine will "kill millions" and that other vaccines have done so. Another conspiracy theory makes the ludicrous assertion that Gates has a secret plan to use vaccines to implant trackable microchips in people. Most Americans still support vaccination, but the few voices of opposition have been growing. A recent study observed that although clusters of anti-vaxxers on Facebook are smaller than pro-vaccination groups, they are more heavily interconnected with clusters of undecided people. One Gallup poll found that one in three Americans would not get a COVID-19 vaccine if it were available today and that Republicans were less likely to be vaccinated than Democrats.

WHY IT'S FALSE: Vaccines save millions of lives every year. Before a vaccine is approved in the U.S., it must generally undergo three phases of clinical testing to show that it is safe and effective in a large number of people. The top COVID-19 vaccine candidates are currently being tested in large-scale trials in tens of thousands of people.

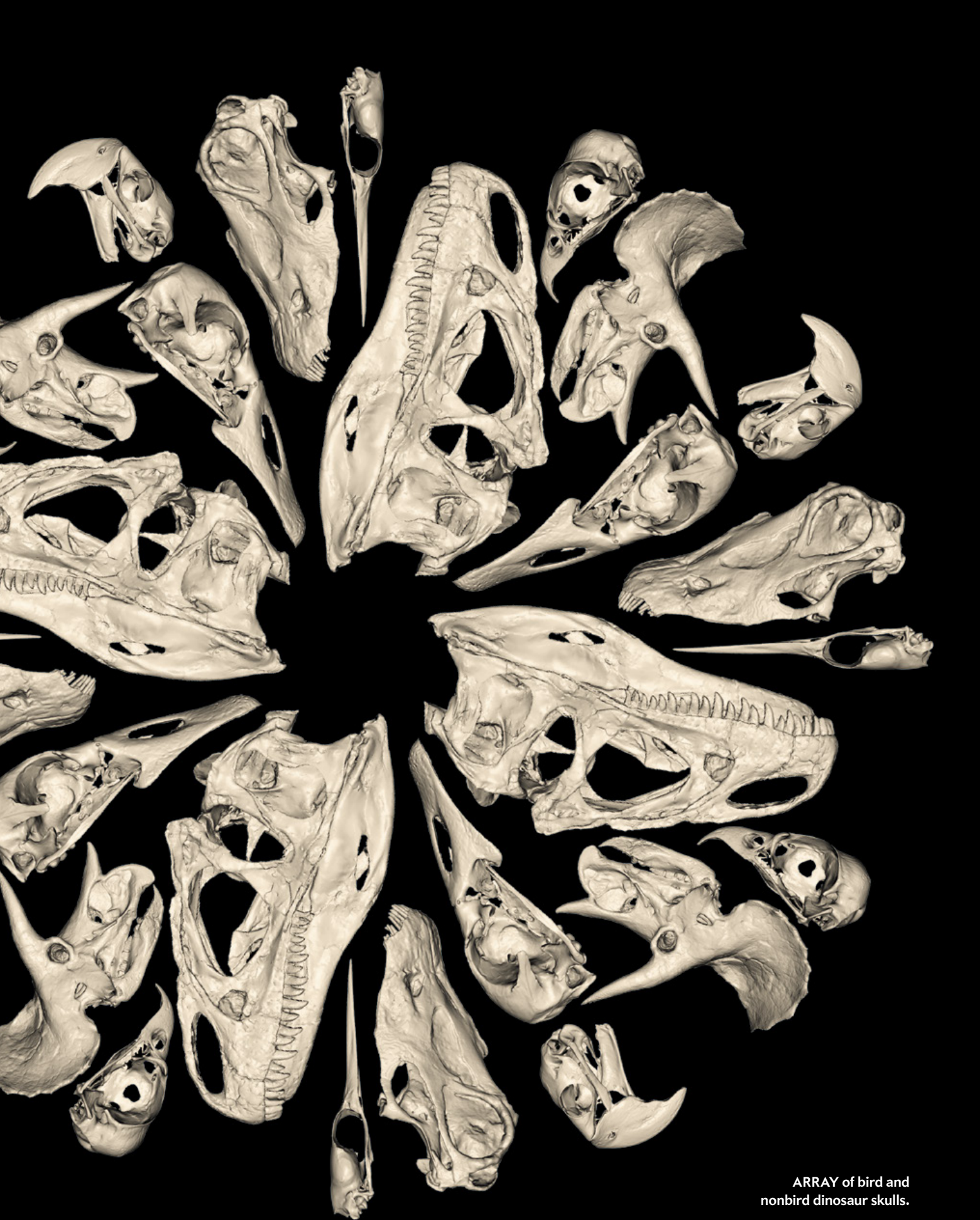
WHY PEOPLE BELIEVE IT: There is good reason to be cautious about the safety of any new vaccine or treatment, and the politicization of the FDA under the Trump administration has raised legitimate concerns that any vaccine approval will be rushed. Nevertheless, previous safety trials of the top vaccine candidates did not find major adverse effects; larger trials for safety and efficacy are now underway. Nine pharmaceutical companies developing vaccines have pledged to "stand with science" and not release one unless it has been shown to be safe and effective.

How Birds Branched Out

Modern birds are incredibly diverse. A new study reveals how they achieved their spectacular evolutionary success

By Kate Wong

RYAN FELICE



ARRAY of bird and nonbird dinosaur skulls.

THIS PAST MAY, WHEN IT FINALLY SANK IN THAT I WAS GOING TO BE STUCK AT HOME FOR A VERY long time because of the pandemic, I took up a hobby that had never especially appealed to me before: birding. I cleaned my neglected bird feeder and filled it with seed, retrieved my binoculars from a gear bag in the basement, and started having my morning coffee outside, slowly learning to identify species based on body size, feather colors, beak shape and song. At last count I had logged 39 species from the confines of my suburban backyard. These hours spent observing birds—the goldfinches congregating at the feeder, the pileated woodpeckers drumming in the trees, the turkeys strutting across the lawn, the ruby-throated hummingbirds hovering above their favorite blooms, the red-shouldered hawks circling overhead—have given me a newfound appreciation for their diversity. And I am seeing only a sliver of the actual richness of avian forms. With more than 10,000 species alive today, birds constitute the most diverse group of land vertebrates (backboned animals) on Earth. How did they come to be so spectacularly varied?

Birds are dinosaurs, the only lineage to survive to the present day. They arose in the Jurassic period, between 200 million and 150 million years ago, from the theropods, a group of two-legged carnivorous dinosaurs whose members include both the behemoth *Tyrannosaurus rex* and the daintier *Velociraptor*. For tens of millions of years birds evolved alongside other dinosaurs, diversifying into a number of small-bodied, fast-growing, feathered fliers, along with a few large-bodied, flightless forms. One group, the so-called neornithines, or new birds—distinguished by their fused foot and anklebones and by certain traits in the bones that support the wings—would eventually give rise to modern avian-kind.

Scientists have tended to view modern bird diversity as the result of a burst of evolutionary activity that occurred after the fateful day 66 million years ago when a six-mile-wide asteroid struck Earth, dooming 75 percent of plant and animal species, including the nonbird dinosaurs and most bird groups. Exactly why the neornithine lineage alone survived this apocalypse is uncertain, although the recent discovery of a 66.7-million-year-old neornithine bird fossil from Belgium called *Asteriornis,* a relative of today's ducks and chickens, suggests that being small and living in a shoreline environment may have helped. In any case, the idea was that after the mass extinction, the neornithine birds had the place largely to themselves. Free of competition from other dinosaurs (not to mention a whole bunch of other vertebrates that also perished, including the pterosaurs, those flying reptiles that had long ruled the skies), birds abruptly exploded into a multitude of forms to fill the many newly vacant ecological niches.

Now a new analysis has turned up intriguing evidence that their extraordinary diversity might not have originated that way. In a study of hundreds of bird and dinosaur skulls, Ryan Felice of University College London, Anjali Goswami of the Natural History Museum in London and their colleagues found that in the aftermath of the mass-extinction event, the pace of birds' evolution actually slowed way down compared with that of their dinosaur predecessors, rather than accelerating as expected. The paper, published in *PLOS Biology,* reveals the rate of evolution during the radiation of a major vertebrate group and hints at factors that may have played a key role in determining its course.

Fossils that preserve the entire skeleton of an animal are extremely rare, so comparative studies of fossil material tend to focus on a particular region of the body. The team looked at skulls because they serve many functions, from supporting sense organs to enabling feeding to attracting mates to defending themselves. "Birds have incredible diversity in the shape of their skulls," Felice observes. Consider hawks versus hummingbirds, he says, or pigeons versus pelicans. "Did birds evolve their highly variable skulls by evolving more rapidly than their nonavian dinosaur ancestors?" Felice asks. That might seem like a narrow question, but "it gets toward an understanding of how diversity evolves," he explains. "If a group of organisms is really diverse, do they achieve their diversity quickly in an explosive burst? Or is it slow and steady?"

To investigate, the team carried out a detailed shape analysis of 391 well-preserved skulls from modern birds

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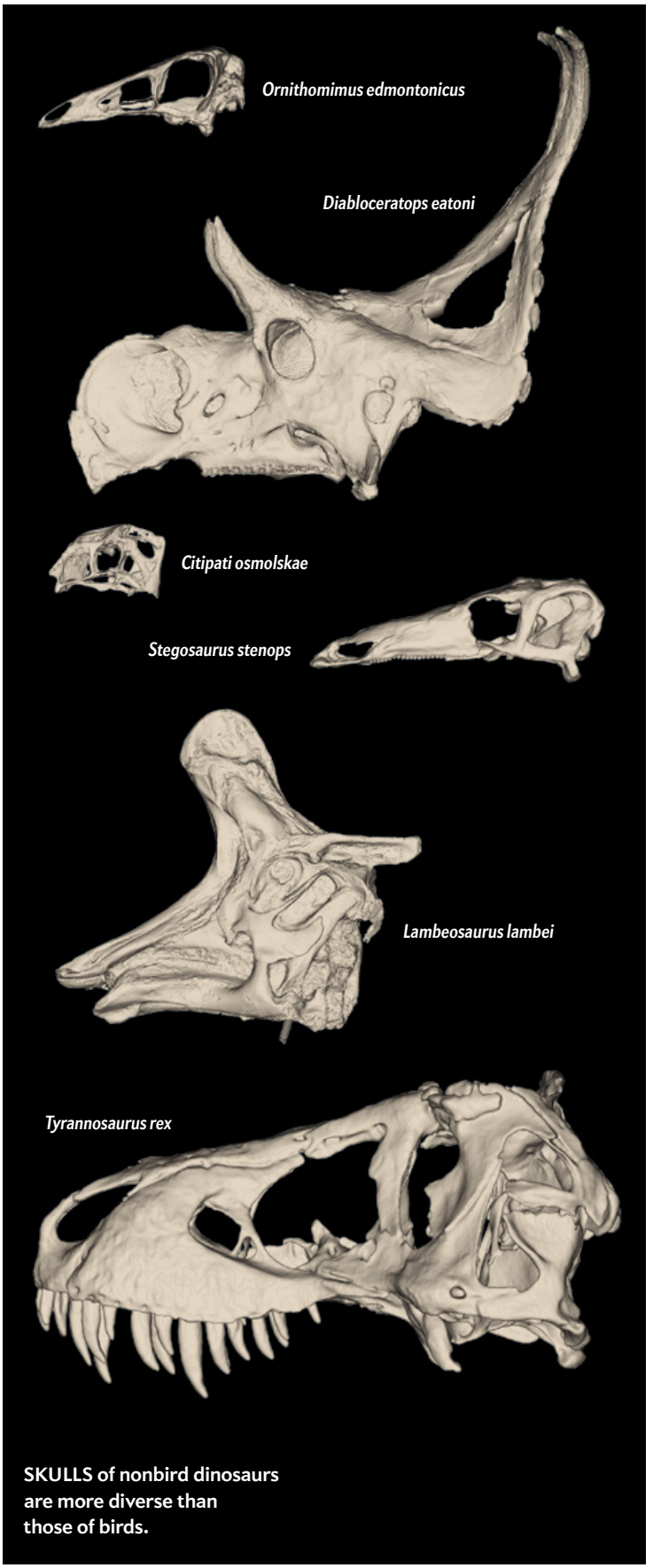
MODERN BIRDS exhibit a myriad of forms, with more than 10,000 species alive today. They are found on every major landmass and body of water on Earth and have evolved to exploit a wide variety of ecological niches. Shown here are a red-shouldered hawk (*1*), a magnificent hummingbird (*2*), a cassowary (*3*) and a flamingo (*4*).

and extinct dinosaurs using high-resolution 3-D scans of the specimens. The scientists used the results to reconstruct the animals' evolution. Typically skull-shape comparisons rest on the use of established landmarks—such as sutures and bumps—that all the various species under evaluation share. But the larger the study group, the fewer the points of correspondence. As a result, investigations that focus on traditional landmarks lose much of the information about skull shape. "Our approach takes those landmarks and uses them as anchors for curves that connect up those landmarks and, in doing so, outline and delimit the individual bones of the skull," Goswami says. "Our automated approach then takes a generic template of points and fits the exact same template to all the specimens in our data set by using the landmarks and curves to identify the regions of interest. So you can get points distributed across the surface of a bone in a consistent way, regardless of whether the bones you are looking at look like the flat, bony structure under the beak of a duck or the tall, biting [snout] of a *T. rex*."

What the researchers found was that dinosaurs evolved 1.5 to three times faster than birds in all regions of the skull. After the mass-extinction event brought the Mesozoic era to a close and ushered in the Cenozoic era, birds branched into most of the major modern groups, from hummingbirds and penguins to birds of prey and songbirds. But they evolved this diversity far more slowly than their Mesozoic dinosaur forerunners. "Their rate of morphological change declines just as they are taking off as a radiation," Goswami says.

Why the sudden deceleration? Goswami thinks it reflects a shift in priorities for skull function. Whereas dinosaur skulls have elaborate display and fighting

ENRIQUE AGUIRRE AVES *Getty Images (1, 2)*; JORDAN CAPITAN *Getty Images (3)*; TASHINA VAN ZWAM *Getty Images (4)*



SKULLS of nonbird dinosaurs are more diverse than those of birds.

RYAN FELICE

structures, as well as complex feeding mechanisms that require large areas for jaw-muscle attachment, bird skulls are mostly dedicated to housing and protecting the animals' comparatively large brain, she explains.

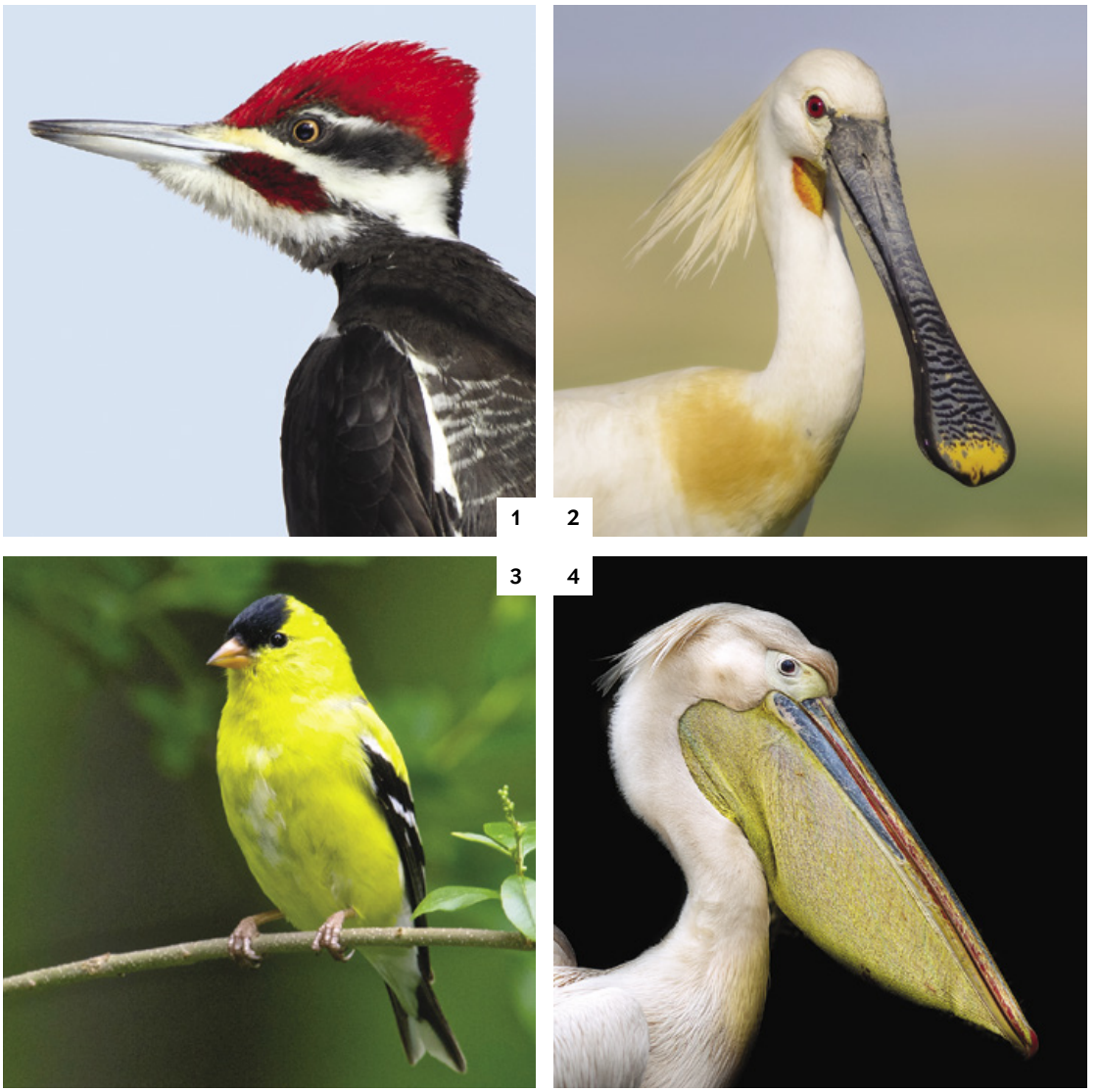
Bird-evolution experts who were not involved in the new research praised the team's methodology and the vast number of species they included in their study.

The finding that dinosaurs had a much faster rate of skull evolution than modern birds might seem strange considering the variety of bills in birds such as spoonbills, flamingos and pelicans, says Daniel Ksepka of the Bruce Museum in Greenwich, Conn. Their sundry shapes suggest a high rate of evolution in the beak, which is a major component of the skull. But a closer look reveals that these distinctive bills are the exception rather than the rule, he says. "There are plenty of groups where dozens of related species share a pretty similar skull shape, like warblers or parrots, suggesting relatively little skull evolution," Ksepka observes.

In contrast, some groups of dinosaurs clearly had sky-high rates of skull evolution. Among the ceratopsians (*Triceratops* and its kin), for instance, "each species had a unique arrangement of horns and crests. And these seem to have evolved rapidly because of their value for attracting mates," Ksepka says. "So many dinosaurs had these elaborate skull ornaments, but they are very rare in birds—the cassowary is one awesome exception," he adds. The large, flightless cassowary, a relative of the emu found in the tropical forests of Papua New Guinea and northeastern Australia, has a prominent bony crest atop its head. "It's likely that feathers took over the display role, as we have plenty of modern birds with plain-shaped skulls but beautiful feathered head crests. Just look at your friendly backyard cardinals and blue jays."

The discovery that bird skulls resulted from relatively low evolutionary rates "is essentially opposite from what we know of the rest of the skeleton," says Stephen Brusatte of the University of Edinburgh, another outside expert. Previous studies by Brusatte and others have focused on parts of the body other than the skull and found that these regions evolved faster in birds than in other dinosaurs. "What this means, I think, is that the origin of birds was driven by rapid and remarkable changes to the skeleton, particularly turning the arms into wings for flight. The heads were less important in this transition, and they probably lagged behind the rest of the skeleton." Early on in their evolution, birds seem to have hit on a head design that worked for them, with such features as a beak, big eyes and a large brain, he says: "Birds didn't need to radically change any of these things in order to adapt to different niches." Instead, Brusatte suggests, "after birds split off from other dinosaurs and went into the skies, they adapted to new niches by changing their body sizes, wing shapes and flying styles more than their heads."

Such mosaic evolution, in which different parts of the body evolve at different rates, is known to have



DIVERSITY of modern birds—from the pileated woodpecker (*1*) to the Eurasian spoonbill (*2*) to the American goldfinch (*3*) to the great pelican (*4*)—has been seen as the product of a burst of evolutionary activity that took place in the aftermath of the end-Cretaceous mass extinction. New research, however, suggests birds evolved their astonishing variety slowly.

occurred in many organisms, including humans. Ksepka notes that the ceratopsians' high rate of skull evolution contrasts starkly with barely discernible changes in their limb bones. Meanwhile modern warblers, he says, exhibit very little change in skull shape but have evolved "a kaleidoscope of color patterns."

But Goswami has a hunch that other parts of the bird skeleton may have also evolved on a relatively leisurely timetable. Nonbird dinosaurs transitioned between bipedal and quadrupedal body plans several times over the course of their evolution and did a lot of different things with their forelimbs, she points out—think of *T. rex*'s puny arms compared with a titanosaur's tree trunks. In contrast, once birds became specialized for flight as their forelimbs morphed into wings, among other changes, they never really evolved completely new body plans—presumably because of the developmental or functional constraints of being a bird. "I expect that future studies with sampling as broad as ours will also start to find that birds are, quite frankly, not keeping up with the pace of evolution observed in the other dinosaurs," Goswami says.

Of course, the birds are no less spectacular for that downturn. They survived fire and brimstone, conquered the skies and diversified into the dazzling array of feathered wonders that share the planet with us today. Slow and steady won the race. SA

FROM OUR ARCHIVES

The Origin of Birds and Their Flight. Kevin Padian and Luis M. Chiappe; February 1998.
Taking Wing. Stephen Brusatte; January 2017.
Winged Victory. Kate Wong; November 2019.

scientificamerican.com/magazine/sa

BRIAN LASENBY *Getty Images (1)*; *Getty Images (2)*; GARY CARTER *Getty Images (3)*; TASHINA VAN ZWAM *Getty Images (4)*

SPACE

ORBITAL AGGRESSION

How do we prevent war in space?

By Ann Finkbeiner

Illustration by John Anthony Di Giovanni

Ann Finkbeiner is a science writer based in Baltimore. She specializes in writing about astronomy, cosmology, and the intersection of science and national security. Finkbeiner is co-founder and proud co-proprietor of a group science blog, The Last Word on Nothing.

On January 30, 2020, an amateur satellite watcher tweeted, "Something to potentially watch." Cosmos 2542, a Russian inspection satellite, was "loitering around" USA 245, an American spy satellite, and, he wrote, "as I'm typing this, that offset distance shifts between 150 and 300 kilometers." USA 245 then adjusted its orbit to get away from Cosmos 2542, which in turn tweaked its own orbit to get closer again. "This is all circumstantial evidence," the watcher wrote, but "a hell of a lot of circumstances make it look like a known Russian inspection satellite is currently inspecting a known U.S. spy satellite."

Laura Grego, an astrophysicist who studies space technology, saw the tweets; she catalogues satellites, so she has been reading amateur watchers' communications, she says, "since before Twitter was invented." One country's satellite stalking another's is exactly what people like Grego, who worry about space war, worry about. Space war is not warfighters shooting one another in space. Nor is it war from the highest of all military high grounds: "Satellites don't 'drop' bombs," Grego says, "and aren't faster, better or less expensive than other ways of bombing." Space war is war on satellites. Cosmos 2542 could have been equipped to interfere with or damage USA 245 or to blow it to pieces. And if it had done so, the U.S. might have retaliated, perhaps by destroying a Russian spacecraft, and we might have had a space war. And then which satellites, and which services civilization depends on, would be destroyed?

For the U.S. more than anyone else, space war could be ruinous. The country relies heavily on its satellites to transmit signals for GPS, credit-card transactions, hospital systems, television stations, weather reports; the list goes on and on. But it depends more than any other country on its military satellites for communication and surveillance. And all satellites—bright and moving in predictable, public orbits—are essentially sitting ducks, nearly impossible to defend; space war is what the military calls "offense-dominant."

The U.S. military's solution to vulnerability is, of course, military. Last December the Department of Defense created the Space Force, saying that Russia and China had "weaponized space" and that space is now a "warfighting domain." Space Force's job is to protect U.S. satellites and to respond to bad behavior by adversaries.

Cosmos 2542, as the then head of Space Force, General John Raymond, sternly told *Time* magazine, "has the potential to create a dangerous situation in space." But Cosmos 2542's stalking turned out not to start a space war. Neither Grego nor the amateur watchers know what Cosmos was doing, but their best guess is that it was something like what Russian trawlers do when they hang around U.S. Navy ships: annoy, or intimidate if possible, and see what they can see. In any case, in mid-March the amateur watcher tweeted that USA 245 had made a small maneuver "that will put it at a distance of thousands of kilometers for weeks to come if not months," and after that Cosmos 2542 took itself elsewhere. Before it did, Grego added her own tweet: "A good time to establish some shared understandings about how close is too close."

Grego is at the Union of Concerned Scientists, a nonprofit that is part of the three worlds—nongovernmental organization (NGO), military and diplomatic—focused on space war. To her, the best way to stop a space war is to enter an international agreement to prevent or limit one. So far negotiations are stalled in international politics. Diplomats never work fast, Grego says, but right now they are "splashing around in the puddle of diplomacy" without getting much done.

So here we are, with the possibility of an escalating space war that would bring certain and incalculable civilian consequences. Yet attempts at diplomacy have been lackluster, and the military's response sounds as aggressive as it does protective. "I don't know if space war is imminent," says John Lauder, a 30-year veteran of the intelligence community's arms-control monitoring efforts, "but there are trends that make space more dangerous. It's not sitting on top of us, but it's moving in our direction at a rapid speed."

SPACE PEARL HARBOR

FOR ALMOST AS LONG as there have been satellites, there have been weapons to use against them and networks to track them. Satellite number one, of course, was Sputnik 1, put into orbit by the former U.S.S.R. on October 4, 1957. Sputnik and its successors were tracked immediately by amateurs with cameras; by February 1959 the Defense Advanced Research Projects Agency had set up the first satellite-surveillance network. The first antisatellite weapon was a missile called High Virgo, launched by the U.S. on September 22, 1959. In 1963 the former U.S.S.R. tested the first "satellite fighter"; in a 1968 test, another satellite fighter entered the same orbit as a U.S.S.R. target satellite, maneuvered next to it and exploded.

After this energized beginning, the U.S. and the former Soviet Union turned their attention from space war to the nuclear balances of the cold war. The U.S. spent the subsequent decades building satellites that were "exquisitely capable and costing billions of dollars and functioning very, very well," says Brian Weeden of the Secure World Foundation. "But they were not built with the idea of having an adversary do something to them." Once the U.S.S.R. collapsed, he says, "America thought it would be dominant in space forever."

Space war appeared briefly on the U.S. agenda in 2001, when a security commission report, headed by Donald Rumsfeld before he left to become secretary of defense, warned of U.S. vulnerability and included the notable phrase "a Space Pearl Harbor." Douglas Loverro, then an air force program director, began advocating for a kind of space force, but "9/11 happened, and everybody forgot about space," he says.

Meanwhile, Grego says, France, Japan, the U.K. and India had launched their own satellites, and more nations had built, bought or operated satellites launched by others. Loverro and other officials, helped by Representatives Mike Rogers of Alabama and Jim Cooper of Tennessee, both on the House Armed Services Committee, kept pushing for a space branch of the military and got nowhere until December 2019, when Space Force was created by presidential fiat. "Magically, we were revived," Loverro says.

This suddenness meant that for a while, Space Force was long on rhetoric but short on specifics and subject to snide remarks from people on the Internet. Its public image was not helped when its first official act was to design uniforms (camouflage, even for soldiers whose field of battle is in front of a computer) and a logo (the delta-shaped wing shared by patches of the U.S. Air Force and the National Reconnaissance Office—and *Star Trek*). By June, however, Space Force and its Combatant Command, U.S. Space Command, were recruiting tech-smart people; coordinating with international allies; deciding which technologies to buy; and running war-game simulations in which teams attack, counterattack and outthink one another. Space war "doesn't have to be inevitable," says Brigadier General Thomas James, commander at Joint Task Force–Space Defense, a component of Space Command, but "it's very serious business, and we take it seriously."

OFFENSE AND DEFENSE

ANYONE ATTACKING SATELLITES can choose from a long, varied menu of weapons. The splashiest option, called a direct-ascent antisatellite weapon, or DA-ASAT, is a missile shot from Earth that blows up a spacecraft. The U.S. and Russia have had DA-ASAT missiles since the cold war. China and India have both tested DA-ASATs on their own satellites. Russia's latest test was this past April.

Another option for attacking satellites is a maneuverable satellite, like Cosmos 2542, which can approach another country's vehicle. Satellites have often used small engines to move for safety reasons, such as to avoid space debris, and maneuverable satellites could be used for refueling or repair. But maneuverable satellites can be dual use, equally capable of colliding with other satellites or of spying on or shooting them. In the past few years the U.S. and Russia have used satellites to deploy smaller subsatellites that roam around: Cosmos 2542 emitted Cosmos 2543, which also stalked USA 245. The U.S. has the X-37B, a smaller, robotic version of the Space Shuttle that does generally secret things, including emitting subsatellites. What these subsatellites can do that parent satellites cannot is also secret and therefore unclear: Weeden says that all we know about them is what we see.

A space war technology that we cannot see, in contrast, is electromagnetic radiation. Satellites can carry equipment to jam others' communications from or to ground stations, or they can mount spoofing attacks to trick other satellites into communicating the wrong things. The U.S., China and Russia routinely jam other countries' links with navigation satellites. Lasers on satellites or on the ground can dazzle or blind spy satellites' imaging sensors, although exactly who has what laser technology with which capabilities is, again, classified or unknown.

In all these hostilities, the U.S. has much to lose. Of the 3,200 or so functioning satellites, the U.S. owns 1,327. Of those, 935 are commercial satellites that provide broadcasting and secure, global communications. Around 200 U.S. satellites are government and scientific satellites that collect data for predicting hurricanes, monitoring droughts, watching the creep of continents and, like the Hubble Space Telescope, understanding the universe. The remaining handful are military and intelligence satellites, most of which are used for communications—command and control of forces, for example, or directing of drones—and for spying. Together the satellites enable modern civilization. They provide the Internet access and GPS navigation and timing signals on which everyone in the world depends and support industries from banking to food supply, the power grid, transportation, the news media and health care.

The few military and intelligence satellites are fundamental to U.S. security and are the source of its vulnerability. The early-missile-warning system uses only 10 satellites, the intelligence community's high-resolution imagery is provided by maybe a dozen, and military command and control communications depend on just six. "The central military problem has been," Grego says, "that we extended ourselves into space, and now we're vulnerable."

This vulnerability matters because no one is sure how satellites can be defended. Perhaps imaging satellites could be fitted with a shutter that reacts fast to too much light, or bodyguard satellites could protect other satellites. Whether such defenses have been put into practice is unknown. "You won't find a lot of official details on the technologies for defense," Weeden says, "due to classification." "Cloaking" a satellite is technically possible, he says, but also expensive and difficult. You can make a spacecraft dark to radar or to telescopes but not to both, and the process can hamper the satellite's performance.

Most efforts at defense tend to focus on deterrence. "The natural place for the military to go is deterrence by punishment," Grego says. "You use ASAT on me; I'll use it on you." The first prob-

Satellites in Space

Much of space is vast and empty, but the portion near Earth is not. The orbital corridors around our planet are clogged with satellites large and small. These spacecraft transmit communications; image the ground; conduct research; and provide broadcasting, GPS, weather forecasts and many other aspects of modern life. One even carries humans. This chart shows each of the thousands of active satellites, as well as their owners, where they are and what they do.

HOW TO READ THE CHART

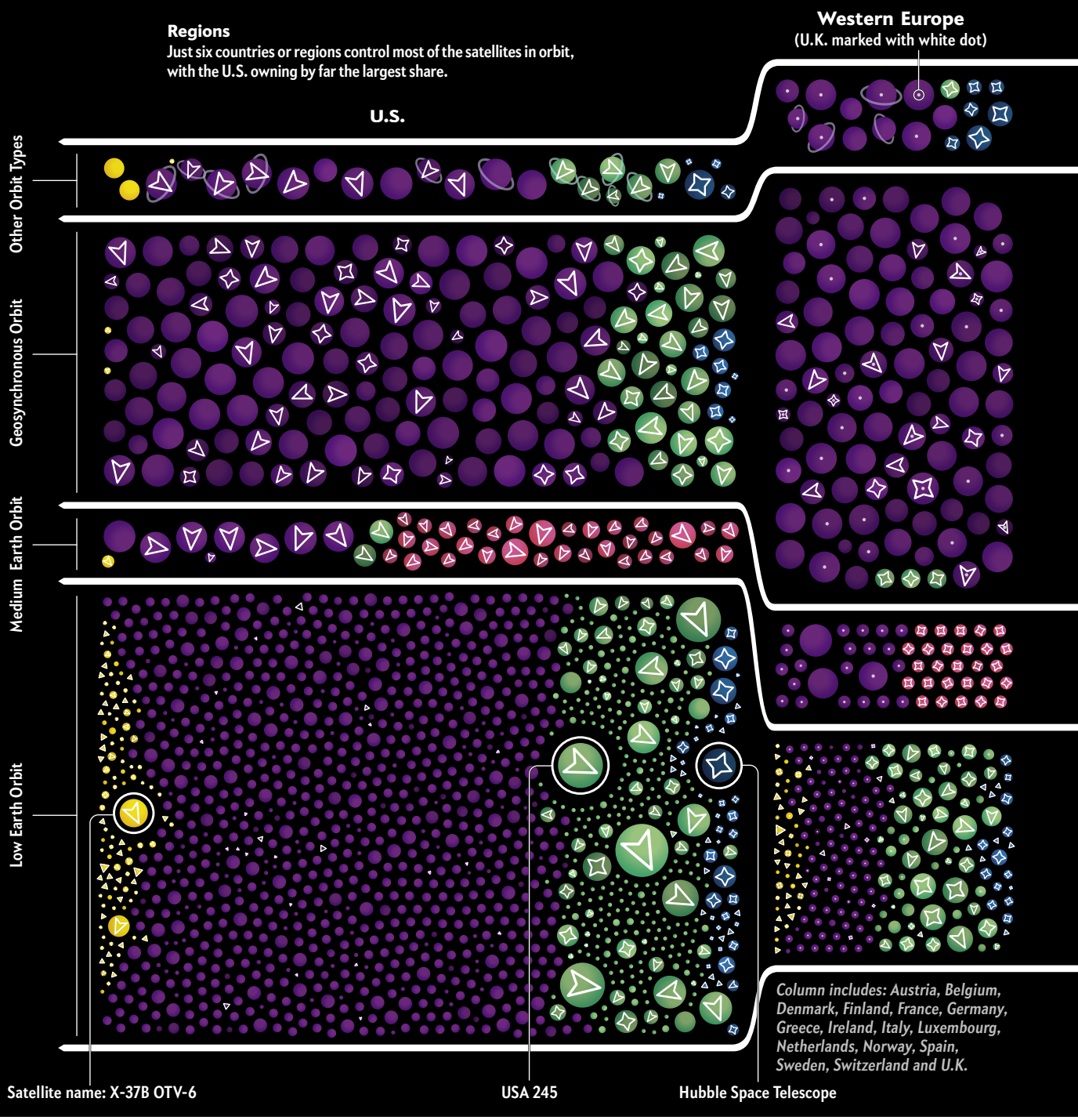
Each of the 2,956 dots below represents an active satellite, as recorded in Jonathan C. McDowell's *General Catalog of Artificial Space Objects* as of September 1, 2020. The dots are organized by controlling region (*columns*) and orbital type (*rows*).

Dot size represents mass of satellite

- 100 kilograms
- 1,000 kg
- 5,000 kg

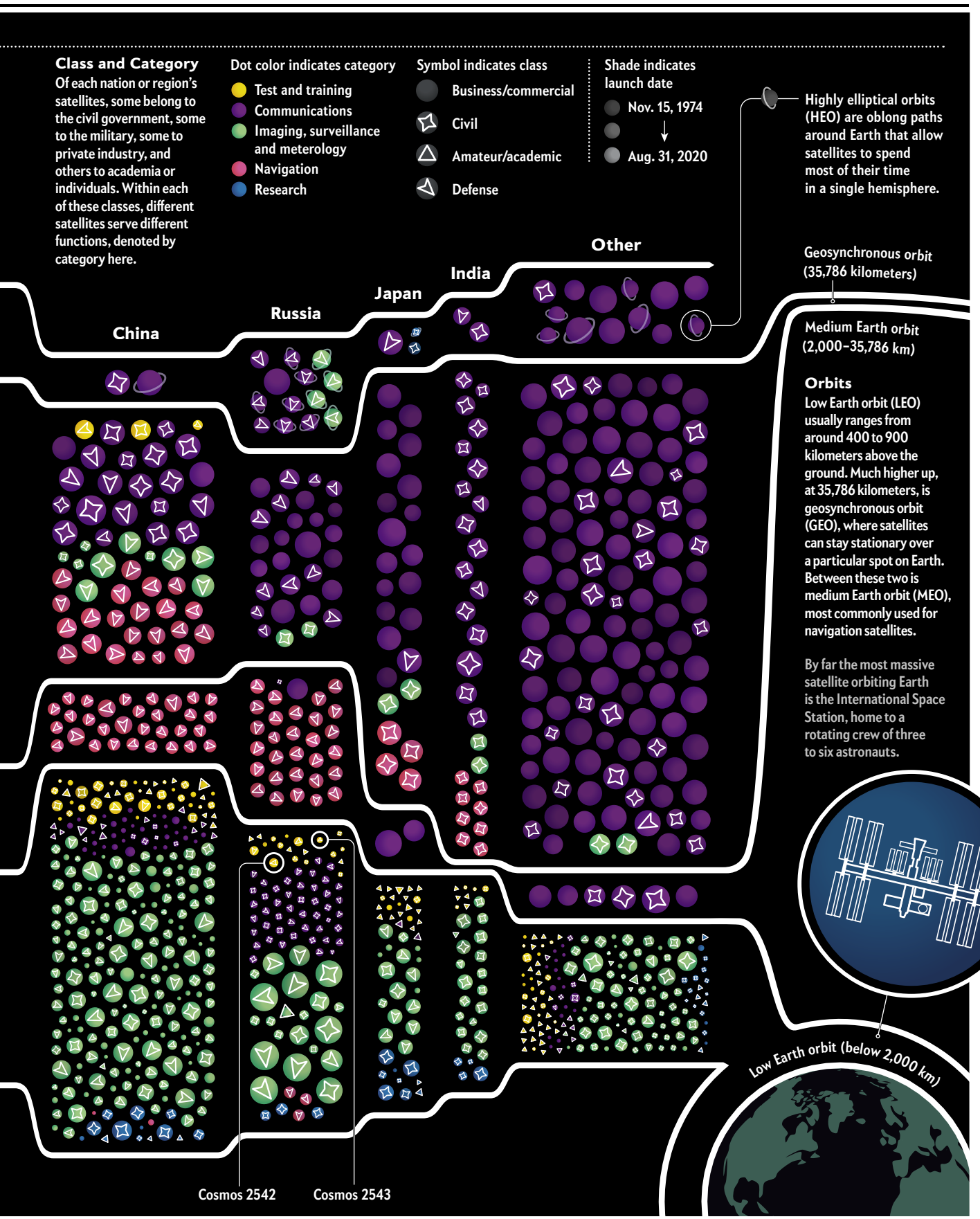
Regions

Just six countries or regions control most of the satellites in orbit, with the U.S. owning by far the largest share.



SOURCE: JONATHAN C. McDOWELL. *GENERAL CATALOG OF ARTIFICIAL SPACE OBJECTS*, RELEASE 1.1.5; SEPTEMBER 2020 https://planet4589.org/space/gcat

Graphic by Nadieh Bremer



lem with punishment, though, is unpredictable escalation. The second is the flip side of U.S. vulnerability—that Russia and China do not need their military satellites as much as the U.S. does. "It's only really the U.S. that needs to conduct military operations anywhere in the world all the time against anyone," Weeden says, whereas most of Russia's and China's need for defense communications is local or regional and "can generally be solved with [other] means."

Alternatively the U.S. could deter attacks by denying their benefits. In other words, a redundant, resilient system that could take losses without losing effectiveness would not be as attractive a target. This is standard deterrence theory; whether the Pentagon is practicing it is not clear. The official Defense Space Strategy, published this past June, avoided this level of detail in the unclassified version of the report.

Deterrence by denial of benefits is effectively being supplied, however, by the commercial space industry. Traditionally the Pentagon has contracted with defense-industry giants such as Lockheed Martin, Raytheon and Northrop Grumman to build its satellites. These spacecraft tend to be the size of large pickup trucks, and one reason for that is economic efficiency, says Colonel Eric Felt of the Air Force Research Laboratory's Space Vehicles Directorate. Whatever new function you need, he says, "just glue it on to whatever you're building." The so-called New Space companies, however—SpaceX, Blue Origin, Virgin Galactic, Planet—have reusable launchers and satellites the size of watermelons at a quarter to a tenth the cost. The savings allow the military to launch more satellites more often, Felt says, spreading out different functions to different vehicles and making replacement easier.

Getting spacefaring countries to agree to behave themselves is not simple. International law governing space is a work in progress.

New Space companies are linking hundreds or thousands of small satellites into large constellations that ensure Internet access and continuous imaging coverage of every spot on the globe and serve as textbook denial of benefits. The Space-Based Infrared System (SBIRS), in contrast, is a constellation of 10 large early-warning satellites and is "a fat, juicy target," says Joshua Huminski of George Mason University's National Security Institute. "I hit three SBIRS satellites, and you don't have early warning." But if SBIRS were a megaconstellation of small satellites, he says, "I take out three, and it's annoying, but the constellation will heal itself."

Felt says that Space Force is developing close relationships with New Space companies, is adopting New Space's rule for ordering new technology not by specification but by function ("I need a five-inch coffee mug" versus "I need a caffeine-delivery system") and is buying good-enough commercial imagery with a credit card.

SPACE DIPLOMACY

BY MID-JULY, months after Cosmos 2542 emitted Cosmos 2543 and drifted away from USA 245, amateur trackers noticed that Cosmos 2543 was suddenly accompanied by a projectile, Object 45915, which then zoomed off, apparently using its own motor, at more than 700 kilometers per hour. Raymond called it an "on-orbit weapons test." The U.K.'s Ministry of Defense tweeted that it hoped Russia would work with international partners toward responsible behavior in space.

Getting spacefaring countries to agree to behave themselves is not simple. International law governing space is a work in progress: NGOs are working on space-law manuals, Weeden says, but "law about conflict in space is so far undefined." International binding treaties are nonspecific or old or on indefinite hold. The United Nations Charter prohibits threats to territorial integrity that extend to outer space. The Outer Space Treaty bans nuclear weapons in space but was signed in 1967, before the great advances in space technologies. In 2014 Russia and China proposed the Prevention of the Placement of Weapons in Outer Space treaty, which prohibits stationing weapons in space; the U.S. does not agree to the proposal's terms but has made no counterproposal. Most recently, the U.N. Committee on the Peaceful Uses of Outer Space agreed on 21 nonbinding guidelines for behavior—for example, "adopt, revise and amend, as necessary, national regulatory frameworks for outer space activities"—which, Grego says, took "a considerable amount of work but do seem a little vague and underwhelming when you read them. You would be disappointed if you hoped they would address space war, but they are not meant to."

The issues on which countries would have to agree are complex and prickly. How do you include everyone—not just the elephantine U.S.-China-Russia triad but all 10 or so countries that can reach space? What is the definition of "weapons" when, say, a robot arm could be used either to replace a defunct sensor or to grab another country's satellite? How to set up lines of communication so that a message of "Sorry, I didn't mean to hit your satellite" can go out before miscalculation and escalation occur? What counts as aggression—hitting another country's satellite with a DA-ASAT missile? Sidling up to another country's satellite? How close is too close? How do you verify that no one cheats on an agreement? And which targets for attacks would cross the line into war, asks John Klein, a fellow at Falcon Research and an instructor at George Washington University's Space Policy Institute? "If you blow up all the GPS satellites—that's critical infrastructure; that's probably war. Take out a small satellite, probably not war."

Meanwhile, Grego points out, countries more or less abide by unofficial norms of behavior: registering new satellites sent into orbit, deorbiting their dying ones to avoid creating debris, not testing DA-ASATs on their own satellites and not destroying another country's satellites. So if a binding treaty is too hard, how about a nonbinding international agreement based on current norms? "The U.S. and Russia are talking about this," Lauder says. "Not that we know in detail what they're talking about, but that they're talking is a good thing. Because nobody can be confident of winning a space war."

Grego agrees with the consensus that it is best to use current norms as a starting point in talks, but she is a little fed up with the pace of diplomacy's progress. The situation "should have been managed years ago by some kind of agreed limits," she says. Shouldn't the State Department get going on this? "We are," says Eric Desautels, director of the Office of Emerging Security Challenges at the State Department. In July 2020 U.S. and Russian officials discussed opening lines of communication to prevent miscalculation and

escalation—the first such discussion since 2013—and expressed interest in continuing the discussion. Meanwhile the U.S. supports a new U.N. agreement that would "break the impasse" on space and also reduce risk of escalation.

ALWAYS WATCHING

THE FUNDAMENTAL NECESSITY of space security is knowing where every satellite is and how it is behaving. Space Force's June 2020 doctrine calls this "space domain awareness." Officially that awareness comes via a global network of sensors on satellites and telescopes on the ground that covers all orbits all the time and tracks everything bigger than 10 centimeters: 3,200 live satellites, as well as 24,000 nonfunctioning "zombies" and pieces of space debris that, in a collision with a satellite at 35,400 kilometers an hour, would cause a catastrophic breakup.

The information is sent to Space Force's 18th Space Control Squadron at the Combined Space Operations Center at Vandenberg Air Force Base in California. Data on the secret satellites are set aside, and the rest go into a public, free, online catalog called Space-Track, from which "conjunction notifications" are issued when two satellites look like they might get too close.

The 18th Space Control Squadron works in a secretive operations center that, judging by press release photographs, values functionality over hominess—a maze of connected computer desks, banks of wall monitors and shiny metal letters spelling out "Where Space Superiority Begins" on a beige wall. In this barn of a room, five to seven members of the 18th Squadron sit next to one another and, to ensure complete and accurate analyses, also next to their colleagues from the U.K., Australia, Canada, NASA and the Department of Commerce, as well as a representative from a collective of New Space companies (all with security clearances). Not on the same floor but available nearby for consultation are representatives from France, Germany and the U.S. intelligence community, including the National Reconnaissance Office. Most people in the 18th Squadron are younger than 25 years, although some experienced "graybeards" bring the average age up to 27. All are tech whizzes. "They've blown my socks off," says Lieutenant Colonel Justin Sorice, the 18th's commander.

The 18th Squadron can say only so much about the details of its job. To find out how to track a satellite, ask the amateurs. They prefer to be called hobbyists; 20 to 100 of them are active, lots are retirees and all are tech-minded. They use binoculars and stopwatches or radio receivers—although sometimes they get fancier—and provide global coverage by being international. They sometimes communicate on Twitter but mostly use a public mailing list called SeeSat, which is how Grego followed them pre-Twitter. "I stopped calling them amateurs a long time ago," she says. "They're quite skilled."

Their low-tech approach means they track mainly the brightest, biggest satellites. They pick spacecraft from Space-Track, from Web sites listing which satellites will be over which cities on a given night, or from rocket-launch notices telling navigators to avoid particular areas. They watch the satellite pass a star, and they hit a timer. As they watch it pass a second star, they check the time to a fraction of a second. By knowing the stars' positions and the time, they can derive an orbit. The last time the secret X-37B, a maneuverable satellite/spy plane, flew, the hobbyists had its orbit in 24 hours.

"The orbit gives a surprising amount of information," says Jonathan C. McDowell, a hobbyist and an astronomer at the Center for Astrophysics | Harvard & Smithsonian. Many satellites, for instance, are in low Earth orbit (LEO), which is up to 2,000 kilometers high. These see the least area but take the crispest pictures, so satellites in LEO are often imagers either doing science, such as monitoring weather, or spying. Others in geosynchronous orbit (GEO), at 35,786 kilometers, hover over and move exactly with one spot on Earth. "You've effectively built a 35,000-kilometer tower," McDowell says, "and taken away the tower," so the satellites in GEO are mostly for communications or broadcasting. Satellites in highly elliptical orbits usually spend most of their time over the Northern Hemisphere and tend to be early-warning or spy satellites. And in sun-synchronous orbits, satellites keep in lockstep with the sun so that the shadows on Earth are unchanging—perfect for spying.

Information also comes from a satellite's behavior. If it is adjusting its orbit, it could be countering Earth's drag or watching one spot on Earth: "During the 1973 war," McDowell says, referring to the Yom Kippur War between Israel and a coalition of Arab states, "satellites moved to give more frequent passes over Egypt." Satellites can "flare" when the sun glints off their flat surfaces; if the flaring is random, the satellite is tumbling out of orbit.

McDowell thinks maybe 10 percent of the satellites they track are classified— spacecraft for military command and control, early-warning equipment, and radio and optical spy satellites—some of which are high-resolution instruments that resemble the Hubble Space Telescope but look down instead of up. These do not show up on Space-Track. The hobbyists are the only open source of information on all countries' classified satellites and, Weeden says, a "primary source of data on American military objects." These space watchers are aware that they bear a responsibility to be careful of speculating about how a spy satellite is being used, McDowell says, but on the whole they are not worried about revealing national secrets: rival countries can buy binoculars and stopwatches, too.

In any case, McDowell thinks the hobbyists are generally apolitical. The enemy, as they see it, is not as another country but the failures of function to which machines are prone, such as RUD (rapid unplanned disassembly), and IOBM (in oceans by mistake). They see themselves, as the 18th Squadron surely must, "as an international community of engineers in space battling Murphy's Law and nature," McDowell says. And they like solving puzzles, finding the gaps in Space-Track left for classified satellites and filling them in: "It's the Sudoku thing," McDowell says.

Ultimately the hobbyists matter in the way that oversight and transparency always matter. Everything about satellites and space war is beset with secrecy—some necessary, some perhaps not. If the hobbyists had not published the Cosmos stalking, Grego says, the U.S. would have been free not to acknowledge a vulnerability, and Russia would have been free to deny that anything had happened. These hobbyists, she says, "can be powerful in their own way." The military and the diplomats work secretly in their own spheres, but if the rest of us want to track the probability of space war, the hobbyists are out there making sure it is as open source as possible. SA

FROM OUR ARCHIVES

Space Wars—Coming to the Sky Near You? Theresa Hitchens; March 2008.

scientificamerican.com/magazine/sa

NEUROSCIENCE

A DISORDER OF MIND AND BRAIN

A mysterious condition once known as hysteria is challenging the divide between psychiatry and neurology

By Diana Kwon

Illustration by Vanessa Branchi

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It all began with a cough.

Three years ago Tracey McNiven, a Scottish woman in her mid-30s, caught a bad chest infection that left her with a persistent cough that refused to subside, even after medication. A few months later strange symptoms started to appear. McNiven noticed numbness spreading through her legs and began to feel that their movement was out of her control. When she walked, she felt like a marionette, with someone else pulling the strings. Over the course of two weeks the odd loss of sensation progressively worsened. Then, one evening at home, McNiven's legs collapsed beneath her. "I was lying there, and I felt like I couldn't breathe," she recalls. "I couldn't feel below my waist." McNiven's mother rushed her to the hospital where she remained for more than half a year.

During her first few weeks in the hospital, McNiven endured a barrage of tests as doctors tried to uncover the cause of her symptoms. It could be a progressive neurodegenerative condition such as motor neuron disease, they thought. Or maybe it was multiple sclerosis, a disease in which the body's own immune cells attack the nervous system. Bafflingly, however, the brain scans, blood tests, spinal taps and everything else came back normal.

McNiven's predicament is not uncommon. According to one of the most comprehensive assessments of neurology clinics to date, roughly a third of patients have neurological symptoms that are deemed to be either partially or entirely unexplained. These may include tremor, seizures, blindness, deafness, pain, paralysis and coma and can parallel those of almost any neurological disease. In some patients, such complications can persist for years or even decades; some people require wheelchairs or cannot get out of bed. Although women are more often diagnosed than men, such seemingly inexplicable illness can be found in anyone and across the life span.

Generations of scientists have tried to understand these bizarre conditions, which have historically been given diverse names, such as hysteria, conversion disorder or psychosomatic illness. These labels have, however, long imposed particular explanations for what many researchers now regard as a complex illness at the interface of psychiatry and neurology. Some are still in use today, but the newest name for these conditions, functional neurological disorder (FND), is deliberately neutral, simply denoting a problem in the functioning of the nervous system.

Patients with FND have long struggled to obtain adequate care. They have been accused of feigning or imagining symptoms, painfully but often fruitlessly probed for childhood trauma and dismissed by doctors who did not know how to treat someone who, based on all the usual tests, appeared to be healthy. "For many, many years physicians have underestimated the prevalence of these disorders and the human toll it takes," says Kathrin LaFaver, a neurologist who specializes in movement disorders at Northwestern University's Feinberg School of Medicine. "These people have really fallen [in the gap] between the fields of neurology and psychiatry."

Over the past decade or so, however, using techniques such as functional magnetic resonance imaging (fMRI), researchers have begun to understand what happens in the brains of patients with this enigmatic

illness. And by applying new models of how the brain works, they are gaining a better understanding of how the condition arises and how it may be treated.

ENIGMATIC ILLNESSES

MORE THAN 3,000 YEARS AGO Mursili II, king of the Hittites, was caught in a terrifying thunderstorm. The experience left him with a temporary speech impediment that went away—only to return several years later, after the monarch woke from a nightmare about the incident. His subjects attributed their king's curious ailment to the wrath of the Storm God, one of the most important deities of the ancient civilization. When modern-day scholars revisited the documents detailing the event, they interpreted it as functional aphonia (the inability to speak).

Like the Hittites, people throughout history have turned to the supernatural—gods, witchcraft and demonic possession—to explain illnesses that today would likely be diagnosed as FND. According to some historical interpretations, the first scientific attempt to account for them emerged around 400 B.C.E., when Greek physicians, including Hippocrates, coined the term "hysteria" to describe a wide collection of ailments, among them paralysis, headaches, dizziness and pain, in the belief that they were caused by the uterus (*hystera,* in Greek) wandering about the body.

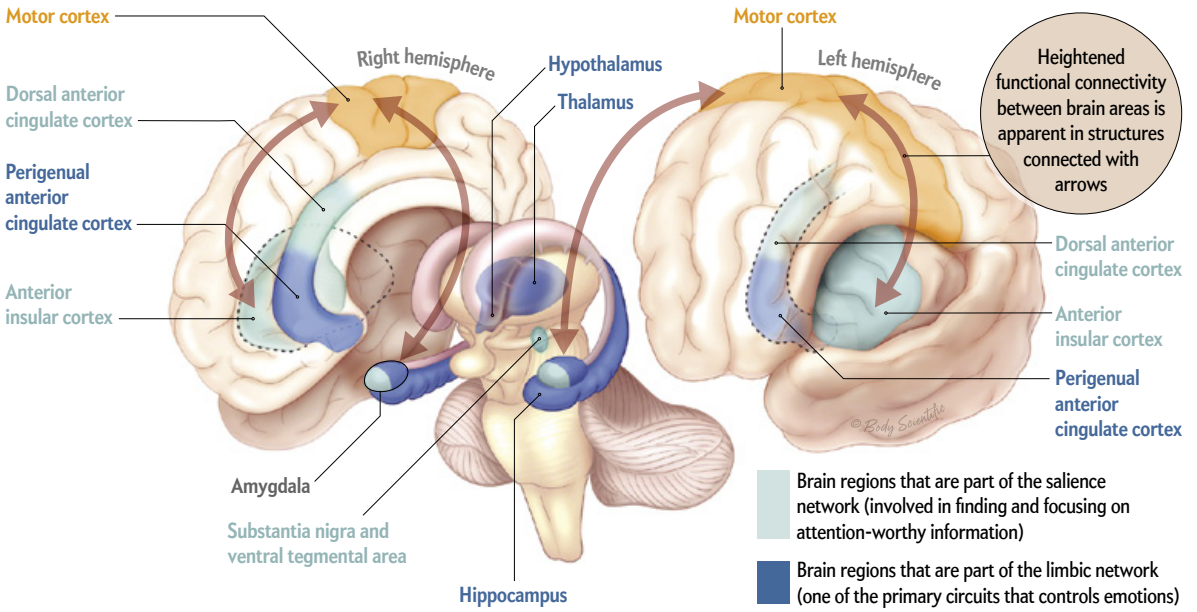
Hysteria had its heyday in the 19th century, when it moved from the womb to the brain. Among several physicians who studied it was Jean-Martin Charcot, regarded by many as the "father of neurology." At the Salpêtrière Hospital in Paris, he painstakingly detailed the symptoms of patients with hysteria and, after they died, conducted autopsies on their brains. Although Charcot was unable to identify any structural aberrations in those subjects, he was convinced that the impairments he saw were associated with unobservable, fluctuating changes in the brain, which he called "dynamic or functional lesions."

Charcot also discovered that, contrary to common belief, male hysteria was not rare; instead it often went undetected. He highlighted, for example, cases of hysteria among workers at a national railway company that had seemingly emerged after minor physical injuries. His work popularized the study of hysteria, inspiring several researchers, including Joseph Babinski, Pierre Janet and Sigmund Freud, to investigate it as well.

Unlike Charcot, however, these men viewed the condition as a disorder of the mind rather than the brain. Freud proposed that it arose when repressed trauma from childhood abuse or other disturbing events was transformed into physical symptoms; accordingly, he called it conversion disorder. That view and label cemented the displacement of the disorder from the realm of neurology to that of psychiatry and became the dogma

The Brain-Body Connection

Patients with physical symptoms (such as paralysis) but no apparent injuries may have functional neurological disorder (FND). Neuroimaging has revealed subtle abnormalities in several brain regions and networks. Studies find, for example, that functional connectivity—meaning correlations in activity—is heightened between areas involved in controlling movement and regions that affect attention and emotion, as shown in the cutaway. These linkages suggest a possible mechanism for the ailment. Activity in circuits associated with a sense of agency, such as the temporoparietal junction and its connections, may also be altered.



SOURCE: "EMOTIONAL PROCESSING IN FUNCTIONAL NEUROLOGICAL DISORDER: A REVIEW, BIOPSYCHOSOCIAL MODEL AND RESEARCH AGENDA," BY SUSANNAH PICK ET AL., IN *JOURNAL OF NEUROLOGY, NEUROSURGERY AND PSYCHIATRY*, VOL. 90; 2019

Illustration by Body Scientific

for much of the 20th century. Perhaps coincidentally, as Freud's influence in psychiatry faded over the decades, so did cases of conversion disorder—to the point where some viewed it as a bygone ailment of the Victorian era.

A century later a new generation of investigators has turned its attention to this condition. Careful observation of patients indicates that despite the drop in diagnoses in the latter half of the 1900s, these disorders have not disappeared. And new research reveals that the condition encompasses both neurology and psychiatry. In 2013 some physicians, concerned that the term "conversion disorder" was not widely accepted by patients and perhaps incorrectly pointed to psychology as an exclusive driver for the condition, lobbied for a change—causing FND to be included as an alternative name for the ailment in the fifth edition of the *Diagnostic and Statistical Manual of Mental Disorders* (*DSM-5*).

Close to a third of patients referred to neurological clinics in Scotland had symptoms that were medically unexplained.

TELLTALE SIGNS

ON A COOL, SUNNY AFTERNOON in February, I watched neurologist Jon Stone of the University of Edinburgh consult with first-time patients at the Anne Rowling Regenerative Neurology Clinic, where his team specializes in diagnosing and treating FND. Stone listened carefully as people described when, where and how their symptoms started. He collected detailed information about their medical and personal histories and conducted a neurological examination. Then, like a detective, he pieced these details together to make a diagnosis.

In recent years FND has gone from a diagnosis of exclusion—a label doctors reserved for patients whose conditions defied all other explanations—to one made after identifying distinct signs and symptoms. These resemble those of other neurological disorders but possess identifiable differences. One example is Hoover's sign, in which weakness in a limb is temporarily corrected when the patient's attention is directed elsewhere. Another is tremor entrainment: when patients with a functional tremor in one arm are asked to start shaking the other at a regular rhythm, the affected hand will start to shake with the same rhythm as the other. This effect does not occur in people with neurodegenerative conditions such as Parkinson's disease. Clear signs of functional seizures include tightly shut eyes, rapid breathing and shaking that lasts for several minutes—features rarely seen during epileptic attacks.

Such indicators have been known to doctors for decades—Hoover's sign, for one, was observed by physician Charles Franklin Hoover in the 19th century. In the past, physicians would hide such signs from patients, Stone explains. But he shows them to patients to help them understand the nature of their condition and notes that physicians are increasingly taking up this practice. Seeing such clues can help to grasp a condition that Stone likes to describe as a "software problem, not a hardware problem" in the brain.

Stone first came across these disorders as a junior doctor in the early 1990s. He found himself fascinated by them; having grown up with a stutter meant that he had experienced being unable to control his own body. And he was disturbed by how those with FND, as he prefers to call the condition, were being treated. The common attitude among medical professionals was that the symptoms were not real—at least not in the same way as those seen in multiple sclerosis or stroke, for example. Many physicians were concerned that they would either fail to identify the true cause of a patient's illness or be fooled by someone faking their symptoms. As a result, patients with FND did not receive the same level of sympathy, attention or care as those with so-called organic neurological illnesses.

Stone decided to dig deeper. During his doctoral studies at the University of Edinburgh, he met Alan Carson, who was training to become a psychiatrist and shared his interest. In 2002 the pair began to assess the scale of the problem by following the referrals to four neurology centers in Scotland over a period of 15 months. Their examination, which included more than 3,700 patients, revealed that 1,144—close to a third—had neurological symptoms deemed as partially or completely medically unexplained. Of those, only four ended up being diagnosed with another neurological issue 18 months after their initial consultation. This work demonstrated how widespread these disorders were.

Eventually Stone and Carson joined forces with Mark Hallett, a neurologist at the National Institute of Neurological Disorders and Stroke in the U.S., who had also been taking strides to advance the field. In addition to conducting his own research, Hallett had begun mobilizing a group of scientists and physicians who could contribute to the study of FND. The community gradually ballooned from several dozens of attendees at a small workshop to a full-blown society for FND, which was founded by Hallett, Carson and Stone and was inaugurated in 2019.

PREDICTIONS GONE AWRY

A YEAR AFTER LANDING in the hospital because of her FND, McNiven was referred to a psychologist. At first, she did not think she needed to be there—her symptoms had been improving with physiotherapy. After several sessions of psychotherapy, however, McNiven made a shocking discovery: she had blocked the memory of certain key events in her childhood. Among those forgotten experiences were years of physical abuse at the hands of a family friend.

Although she had initially been reluctant to consider the role of psychological factors in her illness, McNiven now says that she thinks they do contribute. "I don't

think it's just purely down to that," she tells me. "But it certainly does have a big impact." Many of those who study FND today would agree—with caveats. Unlike Freud, who focused on the role of repressed trauma, researchers now recognize that myriad factors are associated with this condition. These include predisposing factors, such as adverse experiences during childhood, a previous physical injury or mood and anxiety disorders; triggers such as physical injury or a stressful life event; and maintaining factors, such as a lack of access to proper treatment or a patient's responses to and beliefs about the condition. The leading framework for thinking about FND, the so-called biopsychosocial model, takes all these factors into account.

As yet, there is no single, widely accepted explanation for how these influences come together to create FND, but some scientists have suggested that the malady involves arguably one of the most fundamental functions of the brain: predictive processing. Championed by neuroscientist Karl Friston of University College London, predictive processing posits that the brain is constantly making and evaluating predictions by comparing the data generated from our sensory organs to internal models built from previous experience. When mismatches occur between inferences and reality, the brain either updates its existing models or sends commands back down to the body to act in ways that align with our expectations. For instance, if you want to walk, but your leg is not moving, the brain will generate a prediction error that can be resolved if you move that leg. In this way, Friston and others propose, predictions underlie everything the brain does, from perception to movement to decision-making.

Neurologist Mark Edwards of St. George's University Hospital in London and his colleagues have suggested that with FND, this predictive machinery goes awry, so that patients develop abnormal inferences of how their body should feel or function. One of the biggest drivers of this anomaly, according to Edwards, is excessive focus on one's own body. This heightened attention can be attributed to a variety of factors, including an existing physical illness, mood and anxiety disorders, or childhood abuse. When a person experiences a triggering event—say, an injury to a limb or a panic attack—this heightened attentiveness may drive one's brain to develop altered predictions about the body. In some cases, a past experience, such as exposure to sickness in the family, might also help shape these expectations.

Consider someone who falls and badly sprains a leg, resulting in a temporary loss of mobility in that limb. In most people, the brain's predictions about the injured leg's ability to move would get updated once mobility returns. This person, however, has a tendency toward mild anxiety that amplifies the levels of subconscious attention they pay to their body and has been sensitive to health events since the sudden death of a parent. These predisposing factors magnify the sensations associated with injury; in consequence, the internal model of the immobile leg persists even after the limb regains

MAGNUS WENNMAN

Resignation Syndrome

Starting in the 1990s, reports of a mysterious illness began to emerge from Sweden. Children started showing up in emergency rooms in a comalike state—immobile, mute, unable to eat or drink, and unresponsive, even to pain—with no identifiable medical cause, and they remained in this state for months, sometimes years. The patients had some things in common: they were from families of refugees, most of whom belonged to ethnic or religious minority groups from former Soviet or Yugoslav states. And in many, the trigger for their illness appeared to be the rejection of an application for asylum.

Hundreds of cases of the unexplainable illness had been reported by the early 2000s. As the number of afflicted children rose, the nature of the illness became a subject of intense debate. Some opined that the children were faking or that parents were inducing the condition to obtain a residence permit—suggestions that, despite sparking outrage among both clinicians and the public, continue to circulate today. In 2014 the Swedish National Board of Health recognized it as a novel condition, *Uppgivenhetssyndrom* ("resignation syndrome"). Others said it was a manifestation of a known illness, such as severe depression, catatonia or conversion disorder.

Karl Sallin, a pediatrician at Karolinska University Hospital in Sweden, and his colleagues have proposed that the condition is a culture-bound functional neurological disorder. They suggest that resignation syndrome arises when factors such as prior psychological or physical trauma, loss of hope that asylum will be granted and fear of being deported combine with culturally specific beliefs to subconsciously prescribe how the body should respond in the face of extreme external stress. Sallin notes that the apparent specificity of this condition, which is limited to certain refugee communities in Sweden, suggests that the illness is influenced strongly by beliefs prevalent in a particular group. (Reports of a similar condition among refugees waiting for asylum in Australia on the tiny island of Nauru have also emerged, however.) As yet, experts do not agree on what these disorders are.

The number of cases of resignation syndrome has decreased since the peak in the early 2000s. Even so, hundreds of children have been diagnosed with the condition in recent years. —*D.K.*

its function, leading to functional paralysis. (In some ways, this is the opposite of what happens in people who experience phantom limb syndrome. Those people are unable to update the prediction error that occurs when an expected sensation in a missing limb is not met with actual sensory feedback.)

The hypothesis that predictive processing is altered in FND patients has now been tested in a handful of experiments. In a 2014 study, for example, Edwards and his team used a task called force matching, in which a robotic device presses down on a finger and people are asked to match the force with their own hand. Healthy people tend to overestimate the force required by their own hand because the brain's expectations "cancel out" some of its force (a similar explanation applies to why you cannot tickle yourself). People with FND, on the other hand, were abnormally accurate, indicating that the internal prediction system was functioning differently. Even so, much more evidence is needed to prove that this mechanism provides a correct and sufficient explanation for the condition.

Using noninvasive probes, researchers are finding subtle differences in the brains of individuals with functional neurological disorder.

PROBING THE BRAIN

LIKE CHARCOT, contemporary investigators of FND have been examining the brains of patients to find changes associated with the condition. Modern scientists, however, no longer have to wait to conduct an autopsy to peer into their subjects' skulls. Using techniques such as fMRI, researchers have begun to reveal there are indeed differences in the brains of individuals with FND. "We're beginning to identify the dynamic lesion that Charcot was looking for," says David Perez, a neurologist-psychiatrist at Massachusetts General Hospital.

With fMRI, researchers have identified distinct patterns of activity in brain areas such as the temporoparietal junction—associated with a sense of agency—in those with FND, compared with those asked to mimic the same symptoms. These findings help to confirm that unlike conditions such as factitious disorder (a severe form of which is known as Munchausen syndrome), in which patients deliberately act out other illnesses, symptoms in individuals with FND are out of their control.

Another significant discovery from neuroimaging is that people with FND have enhanced connectivity between the motor-control regions and two brain networks involved in emotional processing: the salience network, responsible for detecting and focusing on attention-worthy information, and the limbic network, one of the primary systems controlling emotion. In a 2010 study, for example, Hallett's group reported heightened linkages between the amygdala, a key region in the limbic system, and the supplementary motor area, which is responsible for preparing to initiate movements. Others, such as Perez, have shown hyperconnectivity between motor regions and salience network areas such as the insula and the anterior cingulate. These observations suggest that, at least in a subset of people with FND, the emotional circuitry might be hijacking the motor system, Perez explains.

Perez's team has also found that some risk factors may map onto these circuits. In a study published this year, his group reported that the magnitude of the coupling of the motor regions with the limbic and salience areas of the brain positively correlated with the degree to which patients experienced physical abuse during childhood. Perez emphasizes, however, that this will probably be relevant only to the subset of patients in whom trauma is present: in his study, a significant proportion of patients did not report any childhood physical abuse. Still, he notes that these findings point to how a risk factor such as trauma could alter brain circuits in people who develop FND.

Scientists are also investigating how factors such as stress alter brain circuits in FND. Neurologist Selma Aybek of the University of Bern says that although not all patients have a history of trauma or stress, they may possess differences in their biological stress response. Her group has found that, compared with healthy individuals, FND patients have higher levels of the stress markers cortisol and amylase and report being more stressed after taking part in a stressful task. Building on these findings, her team is using neuroimaging to examine whether there is an association between stress-related regions and agency-related regions in FND patients' brains.

Thus, a picture of the pathophysiology of FND patients is slowly emerging. But most of this work has been conducted in patients with motor symptoms, which means that sensory symptoms such as altered vision have yet to be explored. Many of these studies also have had small sample sizes, so findings will need to be validated in larger trials, says Valerie Voon, a neuropsychiatrist at the University of Cambridge, who collaborated with Hallett on several ground-breaking projects. How these neuroimaging findings fit with the predictive-processing model also remains an open question. It is plausible, Perez notes, that many of the areas identified so far may be the circuitry through which the altered predictions arise.

A BRIGHTER FUTURE

IN THE SUMMER after her second year of teacher's college in Scotland, a 19-year-old woman named Rachael Troup was rushed to the hospital with what appeared to be a stroke. Brain scans showed that she did not have a stroke, however, and tests for other neurological diseases came back normal. Eventually Troup was diagnosed with FND. But when she started treatment, it was excruciating. Neither her doctors nor her physiothera-

pists seemed to know much about how to treat her condition, and the exercises they made her do hurt more than they helped. "I was in pain constantly," she says.

After a few months Troup decided to stop going to physiotherapy. At the time the entire right side of her body was barely functioning, and she was using a wheelchair for mobility. After being admitted to the hospital several more times for strokelike attacks, however, Troup met Stone's team and was provided with FND-tailored care. It involved a form of physiotherapy that employs techniques such as distraction to shift the spotlight of attention away from the affected limbs while engaging in exercises to help restore normal control.

For FND patients, shifting focus away from affected limbs is often a crucial part of physiotherapy because, as Edwards's predictive-processing model suggests, attention is critical to the generation of symptoms. With attention deployed elsewhere, the brain's abnormal expectations about movement are unable to take hold. Stone and his colleagues are part of an ongoing U.K.-wide, randomized controlled clinical trial testing this type of specialized physiotherapy for functional motor disorders (a subset of FND affecting movement). In addition to retraining movement, the treatment includes educating patients about how such symptoms could arise and the physical and psychological factors that may underlie it.

To expand the tool kit of interventions for FND, researchers are also testing other alternatives. Another large clinical trial with more than 300 patients assessed the efficacy of cognitive-behavioral therapy (CBT)—a type of goal-oriented intervention focused on changing disruptive patterns of thinking or behavior—for functional seizures. The findings, published in June in *Lancet Psychiatry,* suggest that CBT may not reduce seizure frequency in all patients.

At King's College London, neuropsychiatrist Tim Nicholson and his team are examining a noninvasive method of exciting the brain known as transcranial magnetic stimulation (TMS) as a potential intervention for FND. His group recently completed a feasibility study, and the results were promising enough to initiate a larger pilot clinical trial. There are competing explanations for why TMS might work. It induces a brief muscle twitch that could kickstart the relearning of movement; stimulating brain areas altered in FND might help restore function, or it may have a placebo effect. LaFaver's group at Northwestern is examining the use of meditation and mindfulness practice, which, according to LaFaver, patients have anecdotally reported as helpful for maintaining the benefits of treatment.

Psychological treatments such as CBT currently remain among the first-line interventions for people with FND, according to Perez. There is a pressing need for a range of effective treatments, however: the prognosis remains poor. It is still relatively uncommon for FND patients to completely regain function, and relapses occur often. According to a 2014 meta-analysis of 24 studies, on average 40 percent of patients reported similar or worsened symptoms seven years after their initial diagnosis. On top of that, patients still experience high levels of stigma and have trouble accessing treatment, LaFaver says. "I still think we have a long way to go."

Fortunately, the situation is changing. As researchers' interest in FND surged over the past decade, so did the number of FND clinics around the world. Patients are speaking up as well. In 2012, for example, the international charity FND Hope was established with the aim of raising awareness and empowering patients.

Still, debates linger—and are reflected in an ongoing tussle over the name of the illness. In what fraction of patients are psychological factors present, for example? Do symptoms primarily arise through conversion of stressors, or are other explanations also necessary? One meta-analysis found that reports of stressors in FND patients vary between 23 and 86 percent in different studies. W. Curt LaFrance, Jr., a neurologist-psychiatrist at Brown University, says that it takes more time to identify such stressors than some doctors can devote to an individual patient—which may account for this enormous spread. In his clinic and in the scientific literature, he has consistently seen evidence of psychological stressors having converted into physical symptoms, and, accordingly, he supports use of the term "conversion disorder." Partially reflecting such views, the older name remained when FND was added to the *DSM-5,* but the need to identify psychological factors for a diagnosis was dropped. That excision also remains contentious.

One thing is clear, however: because the condition lies at the crossroads of neurology and psychiatry, insights from both fields will be necessary to solve the puzzle. This blurring of the line between mental and physical illness is a growing trend. Scientists now understand, for example, that stress—a psychological factor—can predispose people to Alzheimer's disease and that inflammation—a physical factor—may give rise to depression. In addition, traditional neurological diseases such as epilepsy and stroke are often associated with mood and behavioral disturbances. "The brain doesn't separate into neurology and psychiatry," Perez says. "We need a new science of brain and mind that really encapsulates that brain health equals mental health and physical health."

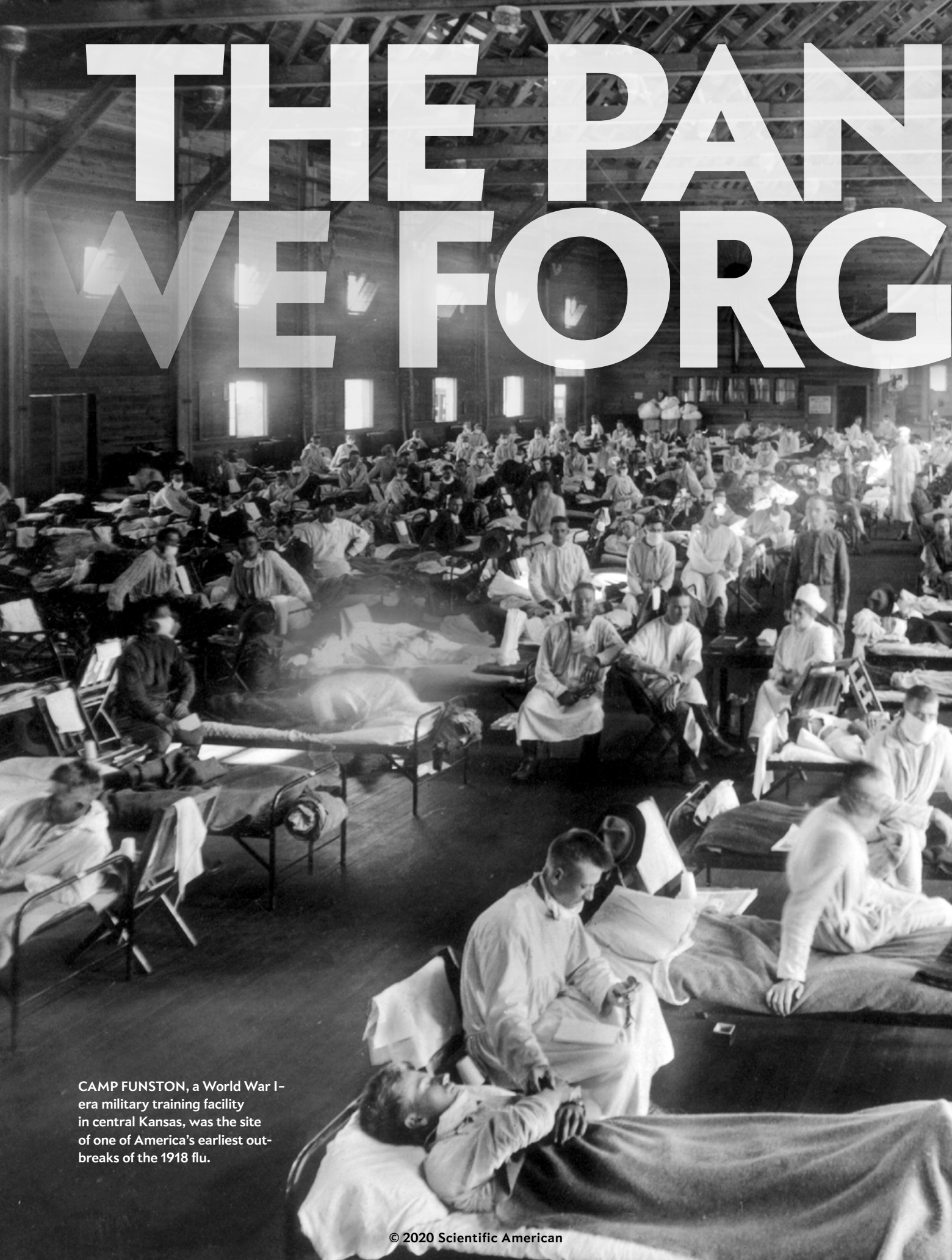
Over the past few years McNiven has frequently used a wheelchair because of her FND. But with the help of both physiotherapy and psychotherapy, she has started to recover. Her symptoms are not gone—she still experiences a lack of sensation in her legs, altered vision and pain—and some days are worse than others. "I constantly feel like I'm fighting against my body," McNiven says. But she hopes to make a full recovery. "You've got to keep that positive attitude to keep fighting through it. There's always hope you can get there with this condition." SA

FROM OUR ARCHIVES

Self-Taught Robots. Diana Kwon; March 2018.

scientificamerican.com/magazine/sa

THE PAN WE FORG



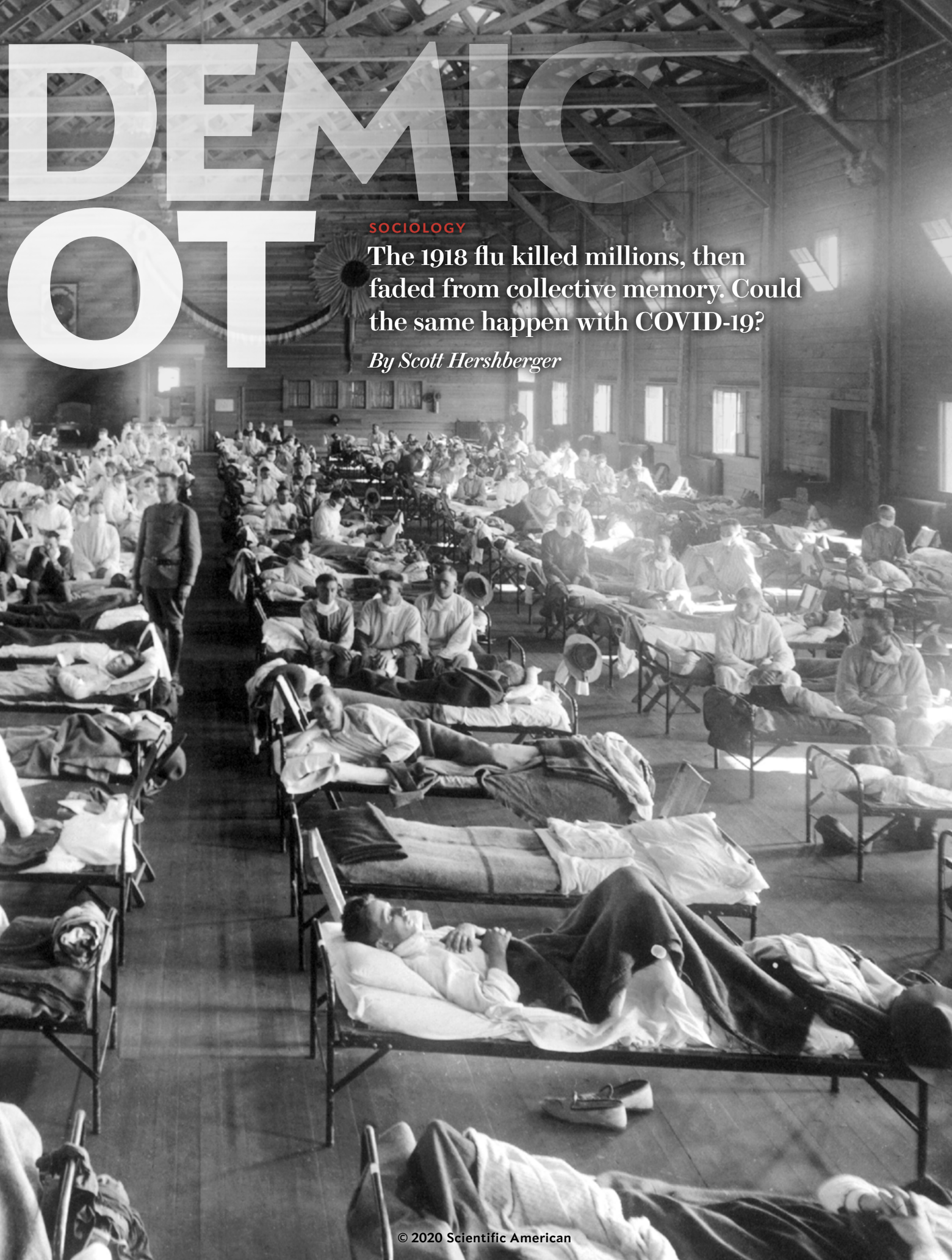
CAMP FUNSTON, a World War I–era military training facility in central Kansas, was the site of one of America's earliest outbreaks of the 1918 flu.

DEMIC OT

SOCIOLOGY

The 1918 flu killed millions, then faded from collective memory. Could the same happen with COVID-19?

By Scott Hershberger



Scott Hershberger was a 2020 AAAS Mass Media Fellow at *Scientific American*.

IN 1924 ENCYCLOPÆDIA BRITANNICA PUBLISHED a two-volume history of the 20th century up to that point. More than 80 authors—professors and politicians, soldiers and scientists—contributed chapters to *These Eventful Years: The Twentieth Century in the Making as Told by Many of Its Makers*. But the book's sprawling 1,300 pages never mention the catastrophic influenza pandemic that had killed between 50 million and 100 million people worldwide only five years earlier. Many history textbooks published in subsequent decades note the 1918–1919 flu pandemic as an aside when discussing World War I, if at all.

Until recently, the pandemic remained strangely faint in the public memory. Monuments and federal holidays commemorate people lost in both World Wars. Museums and movies recount the sinking of the *Titanic* and the Apollo moon missions. But the same cannot be said for the 1918 flu (often referred to as the Spanish flu because of mistaken beliefs about its origin). The event forms a disproportionately small part of our society's narrative of its past.

That such a calamity could fade from our collective memory puzzled Guy Beiner, a historian at Ben-Gurion University of the Negev in Israel. "We have an illusion," he says. "We believe that if an event is historically significant—if it affects many, many people, if it changes the fate of countries in the world, if many people die from it—then it will inevitably be remembered. That's not at all how it works."

Beiner began collecting books about the 1918 pandemic 20 years ago. For a long time, they came in a slow trickle. Now he can hardly keep up. "I have, in my office, three stacks [of novels] waiting for me—huge stacks," he says. Previously a niche topic even among historians, the 1918 flu has been compared with the current pandemic in terms of fatality rate, economic impact, and the effectiveness of masks and social distancing. In March alone, the English-language Wikipedia page for "Spanish flu" received more than 8.2 million views, shattering the pre-2020 monthly record of 144,000 views during the pandemic's 2018 centennial.

The forgetting and rediscovery of the 1918 flu provide a window into the science of collective memory. They also offer clues about how future generations might regard today's pandemic.

WHAT IS COLLECTIVE MEMORY?

PIONEERED in the early 20th century by sociologist Maurice Halbwachs, the study of collective memory has recently become a subject of widespread interest across the social sciences. Henry L. Roediger III, a psychologist at Washington University in St. Louis, defines collective memory as "how we remember ourselves as part of a group … that forms our identity." Nations, political parties, religious communities and sports fandoms, he explains, weave events from their collective past into a narrative that reinforces members' shared sense of who they are.

Researchers often use open-recall methods to study collective memory of well-known historical events. For example, Roediger and several colleagues, including James Wertsch, also at Washington University, asked Americans and Russians to name the 10 most important ones of World War II. Americans most often cited the attack on Pearl Harbor, the atomic bombings of Japan and the Holocaust. Most Russians highlighted the Battle of Stalingrad, the Battle of Kursk and the Siege of Leningrad. The only episode that appeared on both lists was D-Day, known in Russia as "the opening of the second front." Those times people in each country recalled most strongly, the researchers say, reflect that nation's narrative framework, or schema, for remembering the past.

Such a study could indicate what specifics about the 1918 flu people are aware of. But "as far as I know, nobody's done it," Wertsch says. "If you did a survey, you would come up with nothing." Even in making comparisons with COVID-19, he says, few people can cite significant details about the earlier pandemic. Wertsch notes that collective memory seems to depend largely on narratives with a clear beginning, middle and end. "If there's one cognitive instrument that is the most ubiquitous, most natural … it's narrative," he says. "Not all human cultures have arithmetic number systems, let alone calculus. But all human cultures use narratives."

For the countries engaged in World War I, the global conflict provided a clear narrative arc replete with heroes and villains, victories and defeats. But an invisible enemy such as the 1918 flu makes little narrative sense. It had no clear origin, killed otherwise healthy people in multiple waves and slinked away without being understood. Scientists at the time did not even know that a virus, not a bacterium, caused the flu. "The doctors had shame," Beiner says. "It was a huge failure of modern medicine." Without a narrative schema to anchor it, the pandemic all but vanished from public discourse soon after it ended.

Unlike the 1918 flu, COVID-19 has no massive, contemporaneous war to compete with in our memories. And scientific understanding of viruses has dramatically improved in the past centu-

PRECEDING PAGES: ALAMY

ry. Yet in some ways, not much has changed since our ancestors' pandemic. "Even if our experiment in lockdown, in its sheer scale and strictness, is unprecedented, we're thinking in the same way as they were" more than 100 years ago, says Laura Spinney, author of *Pale Rider: The Spanish Flu of 1918 and How It Changed the World*. "Until we have a vaccine, our main way of protecting ourselves is social distancing, and that was their main way of protecting themselves then." The current controversy about masks has a precedent, too: nearly 2,000 people attended a 1919 meeting of the Anti-Mask League of San Francisco.

Research on how political polarization affects the formation of collective memories is scant. Roediger and Wertsch suspect that divisiveness does increase the salience of a person's recollection of an event. But Wertsch questions this effect's potential influence on a cohesive collective memory of the current pandemic. "The virus is just not an ideal character for an ideal narrative," he says.

Even the race to develop and distribute a vaccine is unlikely to yield a strong narrative, according to Wertsch. "It's conceivable that we might see a hero scientist emerge like Louis Pasteur in the 19th century," he says. "But it's noteworthy that our memory of him is precisely of him and not any particular … epidemic." Still, with or without a strong story, COVID-19 will be much better documented than the pandemic that occurred 100 years ago. Could exhaustive media coverage strengthen a collective memory?

MEDIA AND IMAGERY

NEWSPAPERS AND MAGAZINES did cover the 1918 flu extensively while it was still raging. Meg Spratt, a lecturer in communication at the University of Washington, says that U.S. press coverage of the pandemic prominently featured "biomilitaristic" language. Many articles framed the situation as a battle between humans (mainly government officials) and the disease. But the press of the day published "very little on the experience of the victims and survivors themselves," Spratt says. Coverage emphasized experts and authority figures—almost exclusively white men. Spratt also saw evidence that World War I overshadowed the disease. "When influenza deaths surpassed war deaths in Fall of 1918," she wrote in a 2001 paper on the topic, the "*New York Times* ran the news as a small story on an inside page."

Spratt sees parallels between the coverage of the 1918 flu and that of COVID-19. "You still have this emphasis on the public health experts trying to come up with some sort of policies or recommendations to protect people," she says. "But today there seems to be this amplification. I think that comes partly from the different media technology we have." Because the Internet and social media have enabled ordinary people to publicly document their lives during the pandemic, Spratt says, "there's going to be richer material about what people actually went through." In this way, from firsthand accounts of essential workers to reports on racial and socioeconomic disparities in COVID-19's impacts, contemporary media are providing a more complete picture of the current pandemic.

Photographs, too, could help build a collective memory of COVID-19. Psychological research has consistently shown that our visual memory is much stronger than our recollection of words or abstract ideas. That is why widely distributed images can form the backbone of a collective memory, Roediger says. History is filled with such iconic imagery: American troops raising the flag on Iwo Jima; the Twin Towers collapsing on 9/11; Colin Kaepernick kneeling during the national anthem. But "the cameras tend to stop at the door of the sick room or of the hospital," Spinney notes. "We tend to not go into that space." Few images show the dramatic symptoms, such as a blue face and bleeding from the ears, suffered by many who contracted the 1918 flu. Similarly, striking photographs that could reinforce collective memory are scarce in today's news reports of hospitals running over capacity, shortages of personal protective equipment and high death tolls in nursing homes.

Even if no iconic images emerge, though, people will remember how COVID-19 affected them and their families. The same was true for the 1918 flu: in 1974 historian Richard Collier published a book compiling the personal recollections of more than 1,700 people from around the world. But as historians have discovered, collective memories ebb and flow according to the social context of the time.

CYCLES OF REMEMBERING AND FORGETTING

THIS YEAR is not the first time a new pandemic has prompted reexamination of the 1918 flu. There were two more flu pandemics in the 20th century, in 1957 and 1968. In both cases, "suddenly the memory of the Great Flu reoccurs," Beiner says. "People begin looking for this precedent; people begin looking for the cure." Likewise, during the avian flu scare in 2005 and the swine flu pandemic in 2009, Google searches worldwide for "Spanish flu" spiked (although both increases were surpassed by the one that occurred this past March). All the while a growing body of historical research has been fleshing out the story of the 1918 flu, providing the foundation for a significant resurgence of its memory in the public sphere.

Beiner thinks the current crisis will change the way society will remember the 1918 pandemic. Among his collection of books about it, he says, "none of them became the big novel, a book which everybody is reading. I think this might change now." Beiner predicts COVID-19 will inspire a best-selling novel or a major film centered on the flu of 1918. This type of cultural landmark could anchor public discourse about the event, fortifying the present wave of social remembering. As for COVID-19, Beiner anticipates similar "surges in memory and then lapses in memory" over the coming decades. "We're going to have a complicated story," he says.

A stronger collective memory of the 1918 flu could also help create the narrative schema necessary to maintain COVID-19's public profile after today's pandemic ends. If monuments, museums or commemorations are established, they, too, will provide a social framework for continuing discussion of the current crisis. In fact, the New-York Historical Society is already collecting items related to COVID-19 for a future exhibit. "I think there will be much more impact this time because now we are aware that we didn't remember, in a public way, the Spanish flu of 1918," says José Sobral, a social anthropologist at the University of Lisbon.

Wertsch is not so sure. "In a matter of a few years," he says, "we might forget this." He suspects that how the coronavirus pandemic ends—and whether it is followed by other pandemics—will determine how COVID-19 appears in a nation's collective memory. "It's only by knowing the end," Wertsch says, "that we know the meaning of the beginning and the middle." SA

FROM OUR ARCHIVES

Capturing a Killer Flu Virus. Jeffery K. Taubenberger, Ann H. Reid and Thomas G. Fanning; January 2005.

scientificamerican.com/magazine/sa

BLACK DEATH victims in London were buried in a cemetery used from 1348 to 1350. The plague was caused by the bacterium *Yersinia pestis*.

ARCHAEOLOGY

ANCIENT PLAGUES SHAPED THE WORLD

DNA from bacteria and viruses, recovered from human remains, shows how pathogens helped to topple empires and change civilizations

By James P. Close

GETTY IMAGES

James P. Close is a science writer living in South West England.

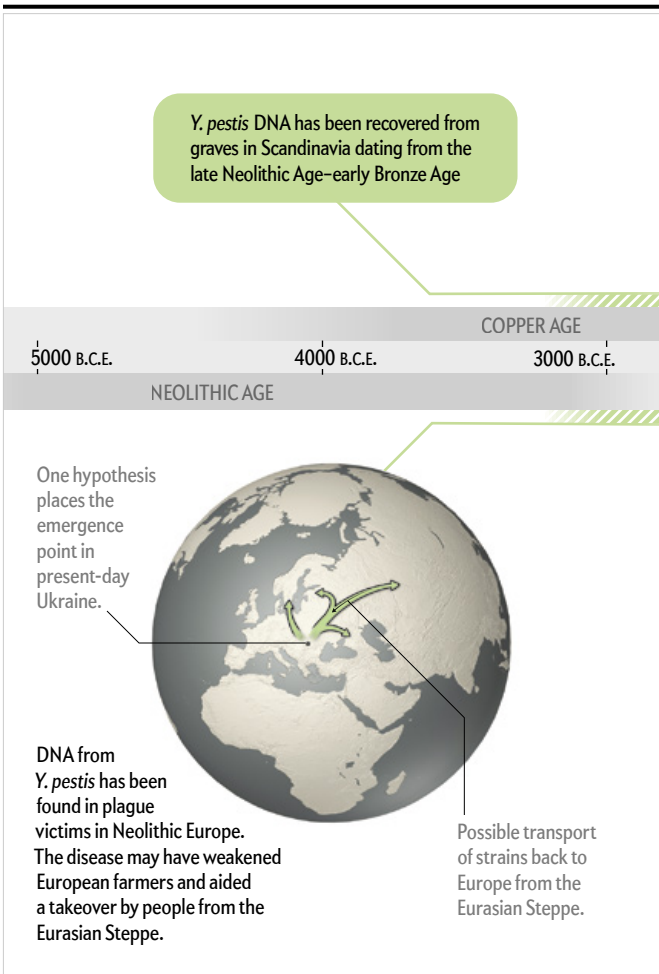
IN 541 C.E., AFTER YEARS OF CAMPAIGNING AGAINST Goths and Vandals, Emperor Justinian I had built the eastern Roman Empire into a vast dominion, nearly encircling the Mediterranean Sea. That year, however, gave the ruler no chance to celebrate. Instead he was attacked by a deadly new foe, an invisible and incomprehensible enemy.

A mysterious plague swept across Justinian's lands and into his capital, Constantinople. Victims spiked high fevers, their armpits and groins swelled painfully, and many became delirious. The emperor himself fell ill. Rumors of his demise filled the panicked city. Historian Procopius, a resident of the city, claimed that on some days as many as 10,000 people died. Justinian managed to survive the contagion, but his empire remained scarred for years afterward, losing its grip on many territories and struggling to maintain control of Rome.

Scientists have debated the identity of this scourge up to the present day. While some blamed the plague on a particularly lethal strain of the bacterium *Yersinia pestis*—the symptoms resembled the medieval Black Death, and *Y. pestis* is the bug behind that devastation—other have argued Justinian was beset by an influenza virus related to the notorious 1918 flu epidemic, which killed an estimated 50 million to 100 million people. Historians have also wondered where the disease started. Many pointed the finger at Egypt because historical accounts noted a similar ailment appeared there just before Justinian's catastrophe.

Now biologists and archaeologists, teaming up to recover ancient DNA from teeth and bones from that time, have been able to resolve this long-standing debate. The teeth hold DNA from *Y. pestis,* not remnants of the flu. Following this strain back in time and across the globe, researchers learned that the plague began not in Egypt but in western China and traveled across the high grasslands of the Eurasian Steppe before hitting Europe.

The disease "had evolved for quite a while before it was seen in the Roman Empire," says Alexander Herbig of the Max Planck Institute for the Science of Human History in Jena, Germany, who used computers to reconstruct DNA changes in the pathogen as it moved from place to place. Over time some of these changes enabled the pathogen to live and spread in new kinds of hosts, extending its devastating reach.

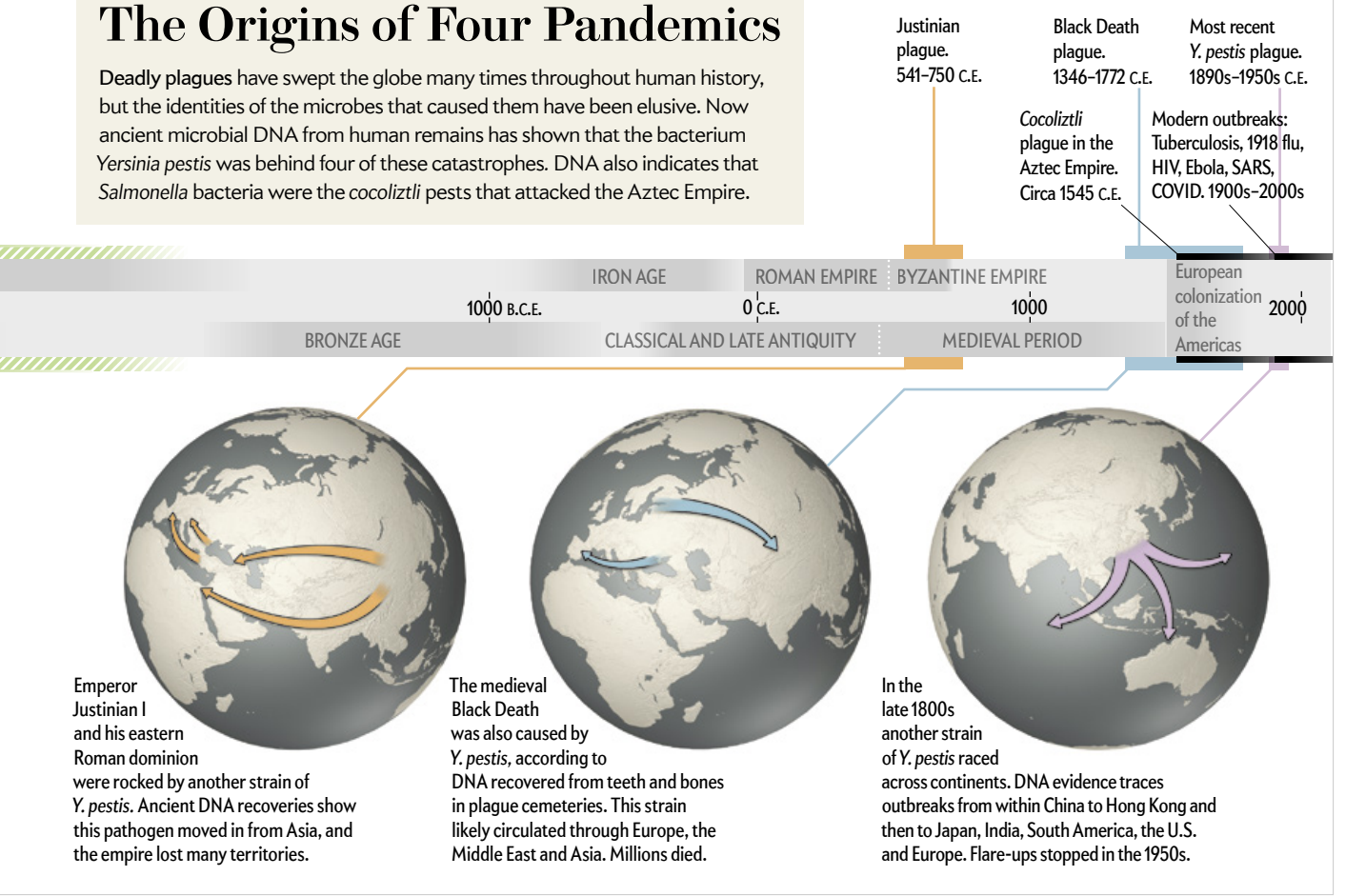


This ability to pull the DNA of disease-causing microorganisms from ancient human remains is helping to fill in a number of big blanks in history books. The molecules show how our history has been shaped by encounters with bacteria and viruses that blew up into pandemics. In addition to the events that shook Justinian's era, scientists have used pathogen DNA to improve our understanding of the origins of the Black Death and the fall of the Aztec Empire. They have even found evidence that a disease during the Bronze Age paved the way for a surge of people out of Asia and into Europe—and those people brought with them technology, culture and genes whose influence can still be seen today.

With these discoveries, certain patterns have emerged about the way microbes turn into plagues. The tiny organisms tend to spread death when they encounter groups of individuals who live packed densely together. They race through populations that have never been exposed before and thus have low levels of natural immunity. Growing international trade and increased human mobility amplify the spread, and pathogens usually have found heightened vulnerabilities among people marginalized and impoverished by society, who have few resources to protect themselves. We are now seeing these patterns again as our current pandemic, driven by the SARS-CoV-2 virus, races across the globe.

The Origins of Four Pandemics

Deadly plagues have swept the globe many times throughout human history, but the identities of the microbes that caused them have been elusive. Now ancient microbial DNA from human remains has shown that the bacterium *Yersinia pestis* was behind four of these catastrophes. DNA also indicates that *Salmonella* bacteria were the *cocoliztli* pests that attacked the Aztec Empire.



Emperor Justinian I and his eastern Roman dominion were rocked by another strain of *Y. pestis*. Ancient DNA recoveries show this pathogen moved in from Asia, and the empire lost many territories.

The medieval Black Death was also caused by *Y. pestis*, according to DNA recovered from teeth and bones in plague cemeteries. This strain likely circulated through Europe, the Middle East and Asia. Millions died.

In the late 1800s another strain of *Y. pestis* raced across continents. DNA evidence traces outbreaks from within China to Hong Kong and then to Japan, India, South America, the U.S. and Europe. Flare-ups stopped in the 1950s.

MOLECULAR CLUES

SCIENTISTS AND HISTORIANS have long been interested in connecting pathogen biology to history, but until about a decade ago attempts were thwarted by difficulties in analyzing DNA from ancient remains (aDNA). Efforts to recover pathogen genomes from Black Death burials, for instance, resulted only in "repeated failure, repeated failure, repeated failure," laments Hendrik Poinar, an aDNA biologist at McMaster University in Ontario. The buried bones were degraded and held only vanishingly small quantities of genetic molecules belonging to the microbes.

Two developments changed the picture in the past decade. One was the recognition by specialists in archaeological genomics that they had been looking at the wrong parts of the skeleton. Teeth, not bones, are the best time capsules. On the outside, teeth are shielded by a tough enamel layer. On the inside, the dental pulp is stuffed with desiccated blood—and the degraded remnants of blood-borne pathogens. Scientists can drill out the interior with a dental drill, dissolve it and, with a little luck, discover some remnants of microbial DNA.

But those samples are scrambled and fragmented. They still need to be stitched back together into long, detailed sequences of DNA so that they can be identified as belonging to a particular bacterium or virus. Next-generation sequencing, a method that speeds up this reassembly, was the second big advance. The technique came into wide use recently thanks to more powerful computers, and it "changed the game entirely," Poinar says. Essentially the method involves sequencing lots of short strings of DNA at the same time, in parallel, and reassembling them into a recognizable genome by connecting them where series of letters (the familiar A, T, C and G of the genetic code) overlap. The approach makes it possible to reconstruct an entire genome from a degraded sample, sidestepping the need to recover a rare long stretch of high-quality DNA.

One of the first successes of this combination of better samples and new technology came in 2011. Poinar and his colleagues recovered a draft *Y. pestis* genome from teeth obtained in a London Black Death burial site. Their find confirmed, after decades of speculation, that this bug was indeed responsible for the medieval pandemic that killed 30 percent or more of the European population between 1347 and 1351. There was nothing especially virulent about this strain, researchers learned over the next five years; it was quite similar to modern *Y. pestis,* which is not nearly as deadly. The high medieval death toll seemed to be driven by an exploding population of runaway black rats, which carried the bacterium through a crowded and malnourished population in burgeoning cities with awful sanitary conditions.

Perhaps the biggest surprise from plague aDNA has come

SOURCES: "ANCIENT PATHOGEN GENOMICS AS AN EMERGING TOOL FOR INFECTIOUS DISEASE RESEARCH," BY MARIA A. SPYROU ET AL., IN *NATURE REVIEWS GENETICS*, VOL. 20; 2019; "*YERSINIA PESTIS* AND THE PLAGUE OF JUSTINIAN 541–543 A.D.: A GENOMIC ANALYSIS," BY DAVID M. WAGNER ET AL., IN *LANCET INFECTIOUS DISEASES*, VOL. 14; APRIL 2014; "EMERGENCE AND SPREAD OF BASAL LINEAGES OF *YERSINIA PESTIS* DURING THE NEOLITHIC DECLINE," BY NICOLAS RASCOVAN ET AL., IN *CELL*, VOL. 176; JANUARY 2019; AND "HISTORICAL *Y. PESTIS* GENOMES REVEAL THE EUROPEAN BLACK DEATH AS THE SOURCE OF ANCIENT AND MODERN PLAGUE PANDEMICS," BY MARIA A. SPYROU ET AL., IN *CELL HOST & MICROBE*, VOL. 19; JUNE 2016

Maps by George Retseck, Graphic by Jen Christiansen

ANCIENT BACTERIAL DNA IN HUMAN TEETH, excavated from a mass grave in Frälsegården, Sweden, came from the plague microbe *Yersinia pestis* (*1*). The grave is about 5,000 years old and held the remains of approximately 78 people (*2*).

from even earlier burials. It turns out that neither the Justinian nor the medieval pandemics were the first times this microbe altered human events on a transcontinental scale.

A PREHISTORIC PANDEMIC

IN 2015 DATA from 101 ancient human genomes, extracted from skeletons buried across the Eurasian Steppe, established that an Early Bronze Age people, the Yamnaya culture, moved down from the steppe around 5,000 years ago, replacing the Neolithic farming cultures of Europe. The newcomers had domesticated horses and new forms of metallurgy and were probably warlike, but still the large-scale population changeover has puzzled scientists because the European groups had done well for centuries. "How on earth could those very well-organized, apparently prosperous European Neolithic societies go into decline?" asked one of the archaeologists involved in this work, Kristian Kristiansen of the University of Gothenburg in Sweden. Some archaeological evidence pointed toward a Europe-wide population crash among the farmers around the time of the Yamnaya arrival, and Kristiansen says he and his colleagues started to wonder if a disease had weakened European society enough to allow for an incursion. In particular, he asked: "Could it be the Black Death?"

When Kristiansen's team had sequenced the 101 ancient steppe human genomes, they had scooped up everything—not just human DNA but a soup of viruses, bacteria and modern environmental contamination. "Between 95 and 99 percent of the data we didn't use," says team member Simon Rasmussen of the University of Copenhagen. "We were just throwing it into the dumpster." But by 2015 the new sequencing technology had given them the ability to sift through the material and compare it with other genomes. "So we took all these data—100 billion small pieces of DNA—and we screened them against the plague," Rasmussen says.

In about two weeks the scientists' machines came up with an answer. Around 7 percent of the ancient remains had traces of plague DNA lingering inside their teeth. Bacteria get into teeth via blood vessels, and "if the bacteria are in the blood, that's really bad," according to Rasmussen. "Very likely these people died from it." This more lethal form of the disease is called septicemic plague; in the most common type, bubonic plague, the bacterium infects the lymph nodes. Because many aDNA samples they examined were in poor shape, Rasmussen also suspects that the plague DNA might be present in an even higher proportion of the material but was too scrambled to detect. He thinks the evidence is "starting to edge toward a likely pandemic." Poinar, however, is more cautious and notes that other factors besides *Y. pestis*—such as famine or warfare—could have contributed to the European population crash.

If the plague bacterium was even part of the cause, the effects can be seen today. Kristiansen's team argues that, just like the later *Y.pestis* outbreaks, this one spread from the steppe into Europe. The Yamnaya likely had some immunity to the bacterium if they had already been exposed to it for hundreds of years. That resistance would have given them an advantage over the plague-ravaged European farmers. So they moved in. With a lighter skin color and a proto-Indo-European language, this group and its migration still influence the look, languages and genes of modern Europe. According to Kristiansen, "it changed the course of European history. It changed the languages in Europe." Genetically, he says, Europeans "are the descendants of those steppe people."

Recently the research group found more evidence buttressing this theory of plague-driven change, when it detected *Y. pestis* DNA in two Swedish Neolithic skeletons dating from around five millennia ago. The disease, it appears, had arrived in Scandinavia just before the Yamnaya takeover. Kristiansen says his colleagues are now scouring "all over the place" for other instances of this early variant. He calls it "the mother of all plagues."

AN EVOLUTIONARY JOURNEY

SEVERAL DOZEN ancient *Y. pestis* genomes now have been analyzed, from various points during the past 5,000 years. Changes in these sequences have enabled researchers to reconstruct an evolutionary history of the bacterium and indicate some early genetic

KARL-GÖRAN SJÖGREN (*1*); PHOTOGRAPH BY TONY AXELSSON (*2*)

alterations that may have helped transform an opportunistic gut pathogen into one of the biggest killers in human history.

In its earliest form—the 5,000-year-old variant—it was unlikely that the bacterium was carried by rat-riding fleas, as was the Black Death version. The older bacterium lacked an enzyme that the modern microbes use to prevent their digestion in flea guts. It probably spread through airborne droplets when its host—person or animal—coughed. But around 4,000 years ago *Y. pestis* gained a gene called *ymt,* possibly from another type of gut bacterium. (Bacteria swap genes frequently.) *Ymt* codes for that protective enzyme, which enabled the plague organism to live inside fleas and travel with the insects, says Johannes Krause, an ancient DNA specialist at the Max Planck Institute for the Science of Human History.

After acquiring *ymt,* the *Y. pestis* bacterium evolved the ability to form a biofilm—and it is this talent that is perhaps the microbe's most sinister innovation. Mutations appeared in a gene that improves the ability to produce an adhesive extracellular matrix, and other mutations hobbled different genes that would normally act to slow or stop matrix production. These changes enabled the bug to coalesce into sticky conglomerations of cells. These build up in the midgut of the flea, blocking its digestive tract. The starved fleas are pushed into a feeding rampage in which they repeatedly bite any mammal around, passing the bacterium with each nip.

PEOPLE AND PATHOGENS

THE aDNA RESEARCH has made it possible to trace the history of other microbes in addition to *Y. pestis,* enabling researchers to identify the dates when many modern human pathogens, including strains of leprosy, tuberculosis, hepatitis B virus and parvovirus, emerged as widespread troublemakers. Those dates, perhaps not surprisingly, occur when humans started to settle down, Krause says.

As civilization developed, distant communities were connected by horse, wheel, then boat—and wherever people went, the microbes went along with them. According to Herbig, long-distance trade facilitated "disease exchange on a global scale." For example, the distribution of ancient hepatitis B and plague genomes follow well-documented human migration routes during the Bronze and Iron Ages. Likewise, tuberculosis was carried by "the crews of Roman trading vessels or the merchants who assembled at waypoints along the Silk Road," according to Caitlin Pepperell of the University of Wisconsin–Madison, whose team used tuberculosis aDNA to estimate that modern strains emerged less than 6,000 years ago—rather than more than 70,000 years ago, as previously believed.

It was not just trade that spread these microbes. Pathogens often exploit multiple animal hosts, and the DNA data show that when our relationships with certain animals became closer, pathogens soon followed. One of the last remaining populations of red squirrels in the U.K., for example, still harbors a medieval strain of leprosy, possibly shipped into England by Viking fur traders. Similarly, a strain of tuberculosis that afflicts people was apparently transported to South America by seals, as revealed by aDNA from a millennia-old Peruvian skeleton. That tuberculosis genome is most closely related to strains found in modern seals and sea lions. "For this population, it makes quite some sense from an archaeological and anthropological view because they did a lot of seal hunting," explains Herbig, who was involved with the research. "They created pottery on which you can find images of people seal hunting and also processing seal meat."

This combination of human factors that increase vulnerability to pathogens—larger populations, greater global connectivity, an ever shifting relationship with the animal world—had a major impact on the New World when Europeans first arrived. The Aztec Empire, centered in Mexico, was invaded by a small contingent of Spanish forces in the early 1500s who toppled the civilization with the aid of disgruntled subjects and rival states. The Spanish then installed a brutal *encomienda* system of harsh treatment, overwork and malnourishment. And the European outsiders seem to have brought other attackers with them as well.

After the initial conquest in 1521, the Aztec population was devastated by one of the biggest pandemics in history. Written accounts from Spanish Franciscan friar Bernardino de Sahagún, who arrived in Mexico eight years after the initial Spanish contact, indicated that an infection killed off as much as 80 percent of the Indigenous population. But the identity of this *cocoliztli* pest (as the locals named it) remained a mystery. Guesses have ranged from hemorrhagic influenza to malaria to typhoid to smallpox. To historians, it was not even clear if the disease was of local origin or was imported by the Spanish.

In 2018, however, aDNA pointed to a likely culprit. Obtaining DNA from skeletons discovered in a *cocoliztli*-era mass grave, Krause and his colleagues established that more than half of the samples had *Salmonella paratyphi C.,* a bacterium that causes a severe intestinal disease. *Salmonella* organisms had not been found in the Americas before European contact, so it was almost certainly shipped across from the Old World. The conquistadors probably carried contaminated food and water on their transatlantic vessels, along with other potential vectors such as chickens, pigs, cattle, and vermin such as rats and mice. All were capable of transmitting disease.

At just this time an environmental misfortune in the Americas helped microbes such as *Salmonella* find a new home. A series of catastrophic droughts hit Mexico in the 1500s—established by tree-ring data published in 2000—and food shortages and population dislocation left people weak and unable to fight off unfamiliar microbial invaders that their immune systems were not prepared for. A civilization crumbled.

Today societies know much more about pathogens and how to fight them than did people 500 or 5,000 years ago. But our current struggles with COVID-19 show that our vulnerabilities to novel diseases have not changed: they often jump to humans from other species, spread via global trade and travel, and become exacerbated by crowding, poverty and malnourishment. The aDNA research reminds us of those enduring facts and shows that some of the biggest events in history were not just defined by powerful figures such as Emperor Justinian I or conquistador Hernán Cortés. They were also profoundly shaped by the microbes their empires helped to spread. SA

FROM OUR ARCHIVES

The Black Death. William L. Langer; February 1964.
How Farmers Conquered Europe. Laura Spinney; July 2020.

scientificamerican.com/magazine/sa

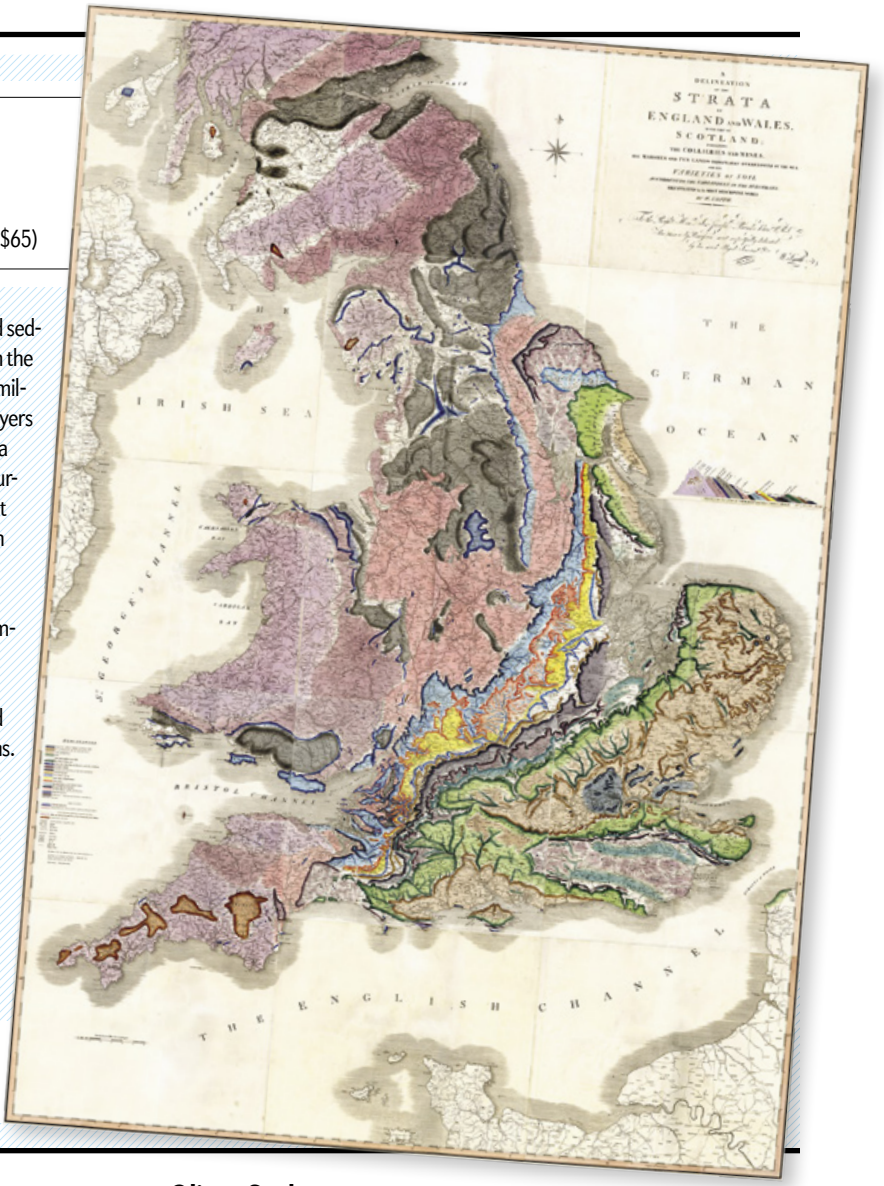
RECOMMENDED

By Andrea Gawrylewski

Strata:
William Smith's Geological Maps

edited by the Oxford University Museum of Natural History. University of Chicago Press, 2020 ($65)

Strata are the ribboned horizontal layers of minerals and sediment that underlie the topography of all the landmasses on the earth and have been revealed by erosion over hundreds of millions of years. Although the practice of mapping geologic layers had begun in the mid-17th century, the science of how strata formed was still nascent. By the late 1700s self-made land surveyor-cum-geologist William Smith brought new breadth and perspective to the study in his work for a mining and prospecting firm. Captured in the many maps and sketches in this stunning collection, the fossils he systematically tagged to particular geologic strata paved the way for a more holistic view of geology that enabled other researchers and industrialists to predict the geologic makeup of large regions. Perhaps the culmination of this pioneering work is Smith's Technicolor map of Britain's geologic deposits, which he labeled with the colloquial names used by miners and quarrymen of the day: Red Marl colored in peach pink, London Clay in sky gray, Chalk in chartreuse. Smith was known to take long "walkings out" in the early morning with hammer and notebook in hand, absorbing the history of the planet, where so many others had merely passed by.



SMITH'S SEMINAL 1815 MAP of England, Wales and part of Scotland. Colors indicate geologic strata.

OXFORD UNIVERSITY MUSEUM OF NATURAL HISTORY (*map*); FOXTOPUS INK (*Wild Thing*)

Wild Thing: Space Invaders

by Laura Krantz.
Foxtopus Ink, 2020 (free podcast)

"Are there other species out there, or are we an anomaly, something special?" asks journalist Krantz during the opening of her podcast's 10-episode second season. She interviews scientists involved in SETI—the search for extraterrestrial intelligence—and astronomers who recently observed the first known asteroid from beyond the solar system. She also talks to U.S. Navy pilots who claim to have seen UFOs and people who believe they have encountered aliens and travels to Colorado's UFO Watchtower, a popular spot for those hoping to sight an unidentified flying object. Through lively storytelling and compelling interviews, Krantz explores the science of how we might discover a new species. She also probes the philosophical questions the search raises and the cultural reasons the question fascinates us: "What does it mean if we find something? And what does it mean if we don't?" *—Clara Moskowitz*

Oliver Sacks: His Own Life

Documentary directed by Ric Burns. Opening date: September 23, 2020. Check screenings at https://bit.ly/SeeOliverSacks

Oliver Sacks was a painfully shy child who felt anguish after a brother developed schizophrenia and his mother called him an "abomination" when she learned he was gay. Fleeing to America for a medical residency, the London native indulged in prodigious amphetamine use and wondered one New Year's Eve whether he would live another year. Burns's documentary, made shortly before Sacks's death from cancer in 2015, traces the blossoming of a brilliant but troubled outsider as he elevated patient case histories to a literary art form by ceaselessly posing the same question: What is it like to be you? Sacks put this query to people with autism, migraines, Tourette's syndrome, agnosia. A measure of his legacy comes in an anecdote noting that 70 percent of applicants for neurology residencies at Columbia University's medical school mention Sacks as a reason for wishing to choose that specialty. *—Gary Stix*

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 *Discerning Experts* (University of Chicago, 2019).

Scientists: Use Common Sense

The WHO's original guidance not to wear masks was a bad move

By Naomi Oreskes

As a scientist and historian of science, I get asked a lot by friends and family to comment on scientific questions. Are vaccines safe? Is red meat bad for you? How much time do we have left to fix climate change? Many of these matters are not nearly as complicated as they have sometimes been made out to be. Vaccination is broadly safe for most people; eating large amounts of red meat is associated with higher rates of death from a number of cancers; and scientists think we have about a decade left to get greenhouse gas emissions under control and avoid the worst consequences.

Lately nearly all the questions involve COVID-19—particularly the matter of masks. The argument for wearing them is pretty straightforward: viruses are spread in droplets, which are expelled when an infected person talks, shouts, sings or just breathes. A properly constructed and fitted mask can prevent the spread of those droplets and therefore the spread of the virus. That is why surgeons have been routinely wearing medical-grade masks since the 1960s (and many doctors and nurses wore cloth masks long before then). It is also why in many parts of Asia, people routinely wear masks in public. A flimsy or poorly fitting face covering may not be much use, but—barring the risk of generating a false sense of security—it is unlikely to do harm. So it stands to reason that, when in public, most people should wear masks. The U.S. Centers for Disease Control and Prevention summarizes: "Masks are recommended as a simple barrier to help prevent respiratory droplets from traveling into the air.… This is called source control."

So why are people confused? One reason is that we have been getting conflicting messages. In April the World Health Organization told the general public not to mask, while the CDC told us we should. In June the WHO adjusted its guidance to say that the general public should wear nonmedical masks where there was widespread community transmission and physical distancing was difficult. Meanwhile CDC director Robert R. Redfield declared that "cloth face coverings are one of the most powerful weapons we have to slow and stop the spread of the virus—particularly when used universally." Today government guidance around the globe varies from masks only for sick people to masks mandatory for all.

Why the contradictory messaging? In particular, why did the WHO say in April not to wear masks? At the time, there was a severe shortage of personal protective equipment; the WHO evidently feared that ordinary people would rush out to buy masks, denying them to medical personnel. According to one report, officials were also concerned that widespread masking would lead to a false sense of security, leading people to ignore other safety measures, such as handwashing and self-isolation.

If the WHO had simply said this, there would have been a lot less confusion. But apparently there was another problem. At the time, no direct evidence existed regarding community spread of this particular virus, and most previous studies were done in clinical settings. The WHO put it this way: "There is currently no evidence that wearing a mask (whether medical or other types) by healthy persons in the wider community setting, including universal community masking, can prevent them from infection with respiratory viruses, including COVID-19."

This is a common pattern in science: conflating the absence of evidence with evidence of absence. It arises from the scientific norm of assuming a default hypothesis of no effect and placing burden of proof of those asserting an affirmative claim. Usually this makes sense: we do not want to overturn established science on the basis of an assertion or speculation. But when public health and safety are at stake, this standard becomes priggish. If we have evidence that something may help—and is unlikely to do harm—there is little excuse for not recommending it. And when there is a mechanistic reason to think it might help, the lack of clinical trials should not be a barrier to acting on mechanistic knowledge. One epidemiologist offered some common sense: "Randomized trials don't support a big effect of face masks, but there is the mechanistic plausibility for face masks to work.... So why not consider it?"

In nearly all areas of science, our evidence is imperfect or incomplete, but this is no excuse not to act on what we know. SA

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Illustration by Jay Bendt

Steve Mirsky has been writing the Anti Gravity column since a typical tectonic plate was about 36 inches from its current location. He also hosts the *Scientific American* podcast Science Talk.

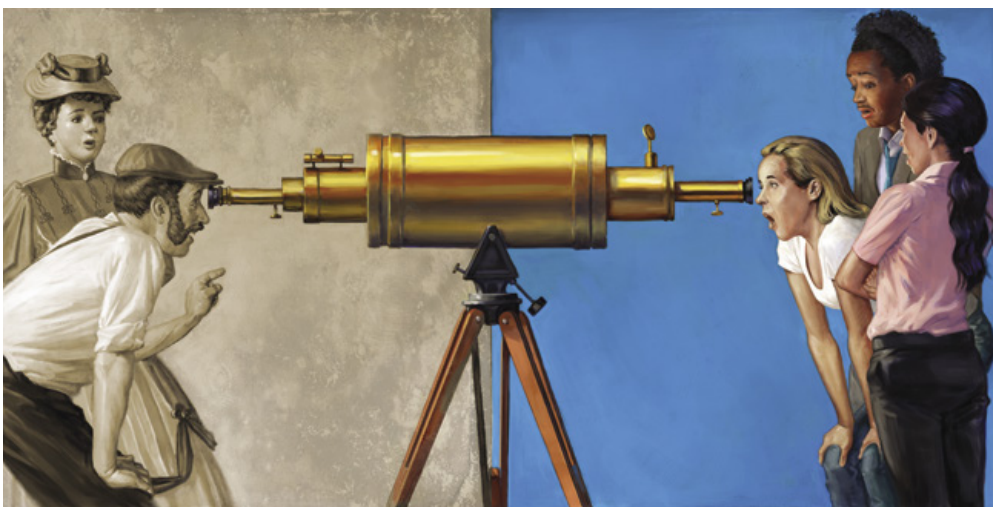
Looking (and Being) Backward

We thought the boat propeller and the telephone were meh

By Steve Mirsky

A friend had a grandfather named August, who passed away on a September 1st. His widow would later say, "The beginning of September was the end of August."

Moving on, as perspicacious readers may have noticed, the end of August 2020 was the 175th anniversary of the first issue of *Scientific American*. In 1921 we published an interview with Marie Curie. In 1950 we ran an article on relativity by Albert Einstein. But even institutions with a long and successful track record are bound to sometimes run off the track. So it comes as no surprise that we've made the occasional boo-boo. Here are some of our best, which in this case means our worst.



Way back in 1846, we shared a terrible notion about boat propellers. "It is truly astonishing," we wrote, "that men of capital in England … suppose that a propeller of any form on the screw principle, can compete with the simple Fultonian paddle-wheel." We missed the fact that as a ship rolls, more of one side of the paddle is submerged, which causes an unbalanced power output. The resulting steering problem is just one reason for the lack today of paddle-wheel aircraft carriers.

In 1869 we floated an idea about how to cross the East River between Manhattan and Brooklyn without a boat or a suspension bridge with big abutments. The proposal involved a large double-decker platform a few feet above the water hanging from a piloted trolley. The trolley would sit on a lightweight, skeletal bridge about 140 feet up and tow the platform back and forth. Transport time from one bank to the other could take as little as one minute. In the end, we decided that a conventional bridge or ferries made more sense than this dangling port of peril. And as a lifelong New Yorker, I feel qualified to note that if there's anything worse than being 140 feet above the East River, it's being just a few feet above it.

We still don't have flying cars. And if humans' driving ability on the ground is any indication, thank goodness. But back in 1915, we were looking forward to transparent planes: "Military authorities await the development of the new French invisible aeroplane.… Over the [aluminum] framework, instead of canvas, is stretched a transparent material … called 'cellon' … a chemical combination of cellulose and acetic acid. Of almost the same transparency as glass, it does not crack or splinter and has the toughness and pliability of rubber." Which is why cellulose acetate is used today for eyeglass frames. Through which you wouldn't see a French invisible plane even if it was a fait accompli.

In 1883 we thought nobody would want telephones: "Despite the fact that recent experiments have demonstrated the possibility of telephoning over long circuits, it is to be doubted if the instrument will be used otherwise than locally.… By telephone it is the sound of a word, and not its vowel and consonants, which the operator receives, and a mistake can easily happen." Yes, that's why the game is called *telephone*. Actually we might ultimately have been right—with the advent of texting, many of us apparently prefer those mini telegrams to talking. As comedian Gary Gulman said of the modern phone call, "To me the phone is just this seldom-used app on my phone. And if you use it on me, I am furious."

Finally, *Scientific American* in the 1920s was enthusiastic about debunking séance holders who claimed to communicate with the dead. We even offered prizes to any mediums who could withstand the scrutiny of our judges, including Harry Houdini. (We never had to pay.) But in 1923 we advocated that some mediums should be compensated for their efforts. "After all, even a medium must live. Nobody has ever suggested the doctor ought to have a job, on the side, as carpenter or hack driver, earning his living from this and giving such time as he can spare from it to the gratuitous healing of disease.… The medium, to the people he serves, gives just as real a service as does the doctor.… Why ask him to give it for nothing?" Years later we think differently about that service. And we no longer have even any small medium largesse. SA

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Illustration by Matt Collins

NOVEMBER

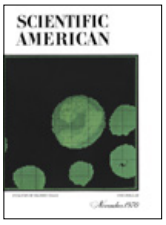
1970 The Promise of Nuclear

"The need to generate enormous additional amounts of electric power while at the same time protecting the environment is taking form as one of the major social and technological problems that our society must resolve over the next few decades. Nuclear reactors of the breeder type hold great promise as the solution to this problem. Producing more nuclear fuel than they consume, they would make it feasible to utilize enormous quantities of low-grade uranium and thorium ores dispersed in the rocks of the earth as a source of low-cost energy for thousands of years. —Glenn T. Seaborg and Justin L. Bloom"

Today more than 400 nuclear power plants are in commercial operation worldwide; only two are fast-breeder reactors.

1920 Weather Data

"During the past hurricane season in the West Indies the U. S. Weather Bureau has carried out a program of upper-air observations in order to determine what relation, if any, exists between the 'winds aloft' (as winds in the upper air are now called by the Bureau) and the movements of hurricanes. Pilot-balloon observations have been made twice a day at stations maintained by the Bureau at Key West and at San Juan, Porto Rico, and at stations maintained by the Navy at Colon and Santo Domingo; data obtained at the Weather Bureau and Army aerological stations in Texas are expected to help in the investigation."



1970

1920


1870

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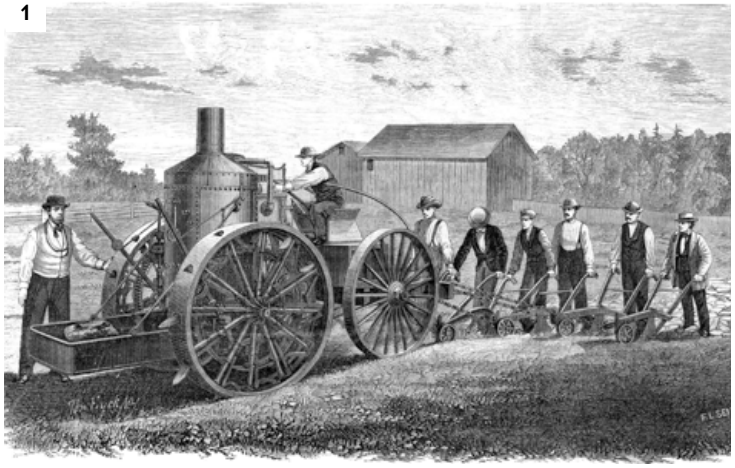


1870: One of the many patented varieties of steam plow from that era.

Before Antihistamines

"Dr. William Scheppegrell publishes statistics showing the beginning and ending of the spring and autumn hay-fever seasons in each State of the Union; the plants chiefly responsible; and a list of 'hay-fever resorts' for all States where such places are known. These resorts are free from hay-fever pollens, where the hay-fever patient can find relief from the disease. As the pollen of most hay-fever plants is very buoyant and will traverse 5 or 6 miles when the winds are favorable, very few places in the country are absolutely free from this troublesome disease."

1870 Steam Power for Farmers

"The accompanying illustration of Redmond's patented steam plow is an accurate copy of a photograph taken of the machine at work in the field. Many attempts at locomotive steam plowing have heretofore proved failures, from the simple fact that the hold of the traction engine on the ground was not equal to the resistance of the plows. In the machine here represented that hold on the ground is secured by the protrusion of a series of twelve anchors through the rim of each wheel. The fuel necessary to keep up steam in these tubular boilers is very little, probably not over six hundred pounds of best coal per day."

SCIENTIFIC AMERICAN, VOL. XXIII, NO. 19; NOVEMBER 5, 1870 (1); *SCIENTIFIC AMERICAN*, VOL. 217, NO. 2; AUGUST 1967. PAINTING BY PHILIP HAYS (2)

2

EPIC TALES

Mechanized Agriculture

CELEBRATING 175 YEARS

Plants, seeded, grown and harvested for us or livestock, are the basic building blocks of our civilization. Issues of *Scientific American* from the early decades after its founding in 1845 reflected a mostly rural nation. The pages are filled with mechanical contraptions (including the steam-powered plow shown above) that look like their inventors were trying to ease the backbreaking labor of farming. By 1967 only 5 percent of the labor force worked in agriculture, thanks to widespread introduction of better technology (such as the mechanical cherry picker—seen at the left—from that year) and the application of biological and chemical sciences to improve crop yields and decrease harvesting costs. —*D.S.*

1967: Mechanical cherry picker. The machine shown was made by the Friday Tractor Company in Hartford, Mich.

Text and Graphic by Katie Peek

The Missing Flu Season

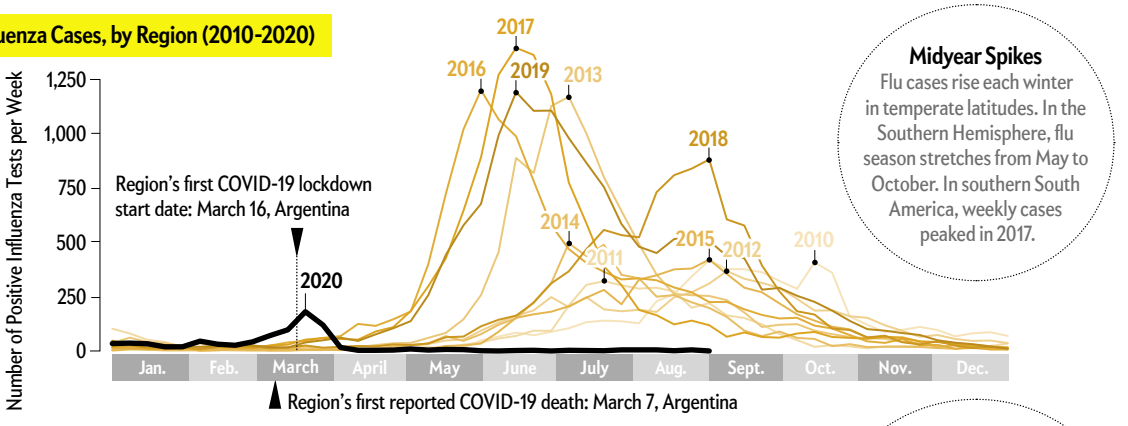
COVID-19 response has thwarted influenza in the Southern Hemisphere

Region by Region
The World Health Organization tracks influenza activity in 18 transmission zones. Three of those regions appear here. Only people who get tested for influenzalike illnesses—typically about 5 percent of those who fall ill—are tallied.

In March, as coronavirus widened its global sweep, one health statistic quickly flattened: influenza cases. In the Southern Hemisphere, flu season would have been just taking off, but cases were virtually nonexistent. "Never in my 40-year career have we ever seen rates … so low," says Greg Poland, an influenza expert at the Mayo Clinic. Although researchers need to study the reasons further, several told *Scientific American* that coronavirus prevention measures—handwashing, mask wearing and social distancing—are working against flu transmission. If those measures continue, Poland says, countries could see the most dramatic drop in influenza cases in modern human history. U.S. health experts still recommend flu shots, however, because not everyone in the country is observing measures to contain the virus and because COVID-19 could perhaps be more threatening in people who contract flu.

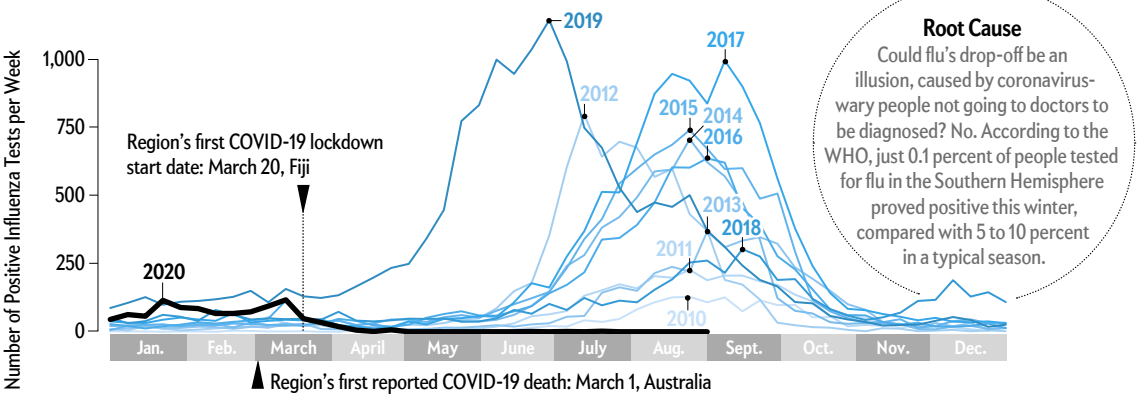
Influenza Cases, by Region (2010-2020)

Temperate South America
(Argentina, Chile, Paraguay, Uruguay)



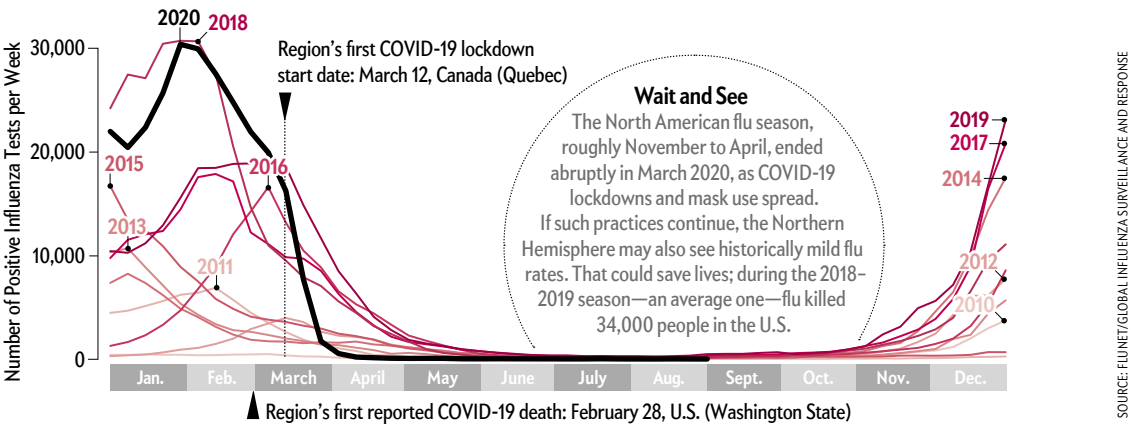
Midyear Spikes
Flu cases rise each winter in temperate latitudes. In the Southern Hemisphere, flu season stretches from May to October. In southern South America, weekly cases peaked in 2017.

Oceania
(Australia, Fiji, New Caledonia, New Zealand, Papua New Guinea)



Root Cause
Could flu's drop-off be an illusion, caused by coronavirus-wary people not going to doctors to be diagnosed? No. According to the WHO, just 0.1 percent of people tested for flu in the Southern Hemisphere proved positive this winter, compared with 5 to 10 percent in a typical season.

North America
(Bermuda, Canada, U.S.)



Wait and See
The North American flu season, roughly November to April, ended abruptly in March 2020, as COVID-19 lockdowns and mask use spread. If such practices continue, the Northern Hemisphere may also see historically mild flu rates. That could save lives; during the 2018–2019 season—an average one—flu killed 34,000 people in the U.S.

SOURCE: FLUNET/GLOBAL INFLUENZA SURVEILLANCE AND RESPONSE SYSTEM, WORLD HEALTH ORGANIZATION (*influenza rates*)